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CAROL
PELLET PLANT

IRON ORE COMPANY OF CANADA

PHASE IV - FINAL REPORT
DEVELOPMENT OF A TECHNICALLY AND ECONOMICALLY
ACCEPTABLE SUBSTITUTE BINDER FOR BENTONITE
FOR USE WITH CAROL LAKE CONCENTRATE

BY TOM. I. MARTINOVIC, P. ENG.
JUNE 10, 1986

IRON ORE COMPANY OF CANADA

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ACKNOWLEDGMENT

On behalf of the Iron Ore Company of Canada and myself, I would like to take this opportunity to express our sincere appreciation and thanks to the Department of Supply and Services Canada and Canmet, especially their designated scientific authority J. M. D. Wilson for the excellent assistance and collaboration during the most important phase of our bentonite substitution program.

Tom I. Martinovic

1.0 SUMMARY

During the period January 1985 to May 1986, the Iron Ore Company of Canada conducted a major program on development of an acceptable substitute binder for bentonite for use with Carol concentrate. The testwork was carried out in the balling circuit at the Carol Pellet Plant and in laboratory and pilot plant-outside research facilities.

The principal purpose of the testwork was to evaluate technical and economical viability of several potential binders as a substitute for bentonite.

The investigation of the potential binders as a substitute for bentonite at the Carol Pellet Plant is an important element in the Company's dynamic program to reduce costs, to improve productivity and product quality and to generally improve the company's competitive position in the iron ore industry worldwide.

This program was cosponsored by the Department of Supply and Services Canada and the Iron Ore Company of Canada.

The potential binders for this testwork were supplied by various suppliers. The testwork was carried out in three phases. Phase I covered evaluation of green ball production using peridur as a substitute binder in one balling circuit at the Carol Pellet Plant. The purpose of Phase II was to determine the effect of peridur as a binder on the physical and metallurgical quality of pellets in a pot grate machine. Phase III of a program included investigation of several other potential binders in a laboratory tire balling and pilot plant disc balling and pot grate firing to determine if desired pellet quality can be produced.

From the observations and test results it can be concluded that the overall program had limited success. In summary, the observations and test results revealed the following:

1. The pot grate test results showed that at a green ball moisture level of 9.0% using peridur as a substitute binder, acceptable pellet quality could not be produced.

2. Among other potential substitute binders tested, Alchem 8C26 and Peat moss indicated good potential.

3. Both of the additives were tested with acid and fluxed pellets. Because filtercake without coke breeze was not available, the optimization of these two products could not be completed. An acceptable pellet quality was not obtained with acid pellets using these binders.

4. The use of Alchem and peat moss as a substitute binder for fluxed pellets showed that an acceptable pellet physical quality could be obtained. As well, very good metallurgical properties were achieved. Reducibility of 1.33 for Alchem and 1.36 for peat moss respectively were achieved.

5. Results indicate that in order to have acceptable acid pellet quality, it may be required to use some bentonite or flux in addition to the organic binder.

6. The test results indicated that peat moss could be used as a potential substitute binder for bentonite and partial or total replacement of coke breeze. Therefore, if further testwork redefines the preliminary findings that an acceptable pellet quality can be produced for both acid and fluxed pellets, this could provide significant cost benefits.

7. With respect to economics of Alchem as a potential binder, additional testwork on optimization is necessary to find out if desired pellet quality can be produced, particularly in acid pellets. As well, test work would indicate binder consumption.

8. Further laboratory and pilot plant testwork is required on both potential binders to redefine their technical and economical viability.

2.0 INTRODUCTION

Bentonite, an inorganic binder, has been used in iron ore pelletizing since the beginning of pellet production in the early 1950's. Over the years, a number of potential bentonite substitutes have been tested. However, no product has been found yet to replace the bentonite with respect to its binding properties and economics.

Although acceptable pellet quality can be produced by using bentonite, its quality deterioration, availability and in particular, its rising cost have become an important considerations at the Carol Pellet Plant of the Iron Ore Company of Canada. Due to the lack of suitable quality bentonite deposits in Canada, the material has to be imported from the United States or overseas. As a result, transportation costs represent about 70% of the total cost of bentonite.

An adverse aspect of bentonite addition to the pelletizing mix is increased impurities in the pellets (product) due to bentonite's chemical composition. It increases gangue content in the pellets and silica (adds about 0.5% SiO_2) resulting in loss of iron units. This iron unit loss must be compensated by increasing the concentrate grade which decreases the overall iron recovery, which consequently raises the production costs. Also, because more stringent pellet quality demands lower silica, bentonite is becoming a less desirable binder.

In order to maintain and possibly enlarge our share of today's competitive iron ore world market, everything possible must be done to reduce our operating costs and improve pellet quality. With respect to binder cost and its effect on pellet quality, an extensive program is underway to reduce bentonite consumption and investigation of some cost effective organic binder substitutes.

In early 1985 the Iron Ore Company of Canada had undertaken an extensive study on "Development of technically and economically acceptable substitute binder for bentonite for use with Carol concentrate". Since this program was cosponsored by the Department of Supply and Services Canada and the Iron Ore Company of Canada a reference should be made to DSS file number 03SQ.23440-4-9316.

This joint study on investigation of a potential substitute binder for bentonite was divided into three phases:

- Phase I of the program covers feasibility of using peridur as a potential substitute for bentonite. The testwork was carried out on one balling circuit at the Carol Pellet Plant. The primary purpose was to find out if an acceptable green ball quality can be produced. The detailed findings are shown in a report of March 29, 1985, Appendix I.

- The purpose of Phase IIA was to determine the effect of Peridur as a binder on the physical and metallurgical quality of fired pellets. The pilot plant balling and pot grate testwork was carried out to investigate a wide range of process parameters to meet the objective. Because the results of Phase IIA proved unsatisfactory, the second stage of this phase (IIB) was cancelled. For the details on Phase IIA see report of August 15, 1985, Appendix II.

- Phase III of the program covers the following scope of work:

  a) Investigation of several products as a potential substitute binders for bentonite using the laboratory balling tire to determine if desired green ball quality can be produced.

  b) Based on the green ball properties obtained with tire balling, two products showed good potential and were selected for further testwork.

c) Evaluate the effects of the two potential binders on physical and metallurgical properties of fired pellets in a pilot plant test equipment, i.e. 1 meter balling disc and a pot grate machine for pellet firing.
The details of outcome of this phase are shown in a report of June 06, 1986, Appendix III.

- Phase IV of a joint program between the Iron Ore Company of Canada and the Department of Supply and Service Canada summarizes the outcome of Phase I, IIA and III, and is shown in this report.

The work on this project was conducted under the auspices of the Canada Center for Mineral and Energy Technology, Energy, Mines and Resources, Canada. The designated Canmet's scientific authority was J. M. D. Wilson, who continuously monitored the progress of the program and closely worked with the Iron Ore Company of Canada's Engineers.

It should be noted that a product identical to Alchem 8C26, fully replaced bentonite at Whyalla Pellet Plant, South Australia since April 1985. Since their flow sheet employs dry grinding, about 50% water is added in the balling circuit. Organic binder is added with this water in a balling circuit. P-Kay mixers are no longer used. Addition rate as low as 0.1 kg/t pellets is achieved, which is several times lower than the one experienced during testwork with Carol concentrate. Most of the difference is attributed to type of ore, grinding degree and flow sheet. However, this gives an indication that further optimization of Alchem with Carol Concentrate is possible. Savage River, Pellet Plant, in Australia is also testing the same product. Their progress is slower because of their flowsheet (wet grinding).

3.0 PHASE IV - OBJECTIVES

The principal objective of Phase IV was to outline overall findings and test results of all three phases of the program.

The summary of the objectives of the individual phases is as follows:

Phase I: Evaluation of Peridur as a potential substitute binder for bentonite. The scope of testwork covered Peridur addition to the Carol concentrate in one balling circuit at the Carol Pellet Plant. The primary propose was to find out if acceptable green ball quality can be produced with use of Peridur as a substitute binder for bentonite.

Phase II: To determine effect of Peridur on the physical and metallurgical properties of fired pellets on a full scale pot grate equipment; i.e. 1 meter balling disc and pot grate firing.

Providing the pot grate test results are satisfactory with Peridur, the second stage of Phase II would include the commercial plant testwork in one pelletizing machine at the Carol Pellet Plant.

Phase III: Investigation of several products as a potential substitute binder for bentonite:

a) Laboratory tire balling to see if desired green ball quality can be produced. Select the two most suitable products for further testwork based on green ball quality.

b) Carry out further testwork in a pilot plant disc balling and pot grate firing to determine the effect of these two binders on the physical and metallurgical quality of fired pellets.

4.0 TEST RESULTS AND DISCUSSION

The details of test results and the discussion of the individual phases of the program on the development of a substitute binder for bentonite are shown in the individual reports for each phase:

- Report on results of test Phase I, Appendix I
- Report on results of test Phase II, Appendix II
- Phase III - Final report, Appendix III

These reports are attached in the appendix of this report.

5.0 CONCLUSIONS

An overall assessment of the program on development of a technically and economically acceptable substitute binder for bentonite for Carol concentrate leads to the following conclusions:

1. The testwork using Peridur as a binder on one balling circuit at the Carol Pellet Plant showed that balling operations were carried out without major problems. On the other hand, the green ball quality produced with Peridur was generally lower compared to bentonite based green balls.
2. The pot grate test results revealed that at a green ball moisture level of 9.0% using Peridur as a substitute binder, an acceptable pellet quality was not produced.
   It should be noted that these results were obtained using Carol concentrate and are not necessarily applicable to other types of ores and flow sheet of other pelletizing facilities.

3. Laboratory tire balling test results revealed that among the several potential binders tested, Alchem 8C26 and peat moss showed good potential for bentonite substitution. On the basis of green ball properties obtained, these two potential binders were selected for pilot plant testwork.

4. Based on the laboratory tire balling results, the addition rates of 0.125% for Alchen 8C26 and 1.0% (dry) for peat moss with 0.15% NaOH respectively were chosen for the initial pot grate testwork. Peat moss was also ground to about 30% less than 200 mesh and dried to 70% moisture content. The pot grate test results showed that desired pellet quality was not produced in spite of acceptable green ball properties.

5. Additional laboratory and pilot plant disc balling tests were carried out to improve green ball quality. These tests indicated that good green ball quality was achieved with an addition of 0.09% Alchem sprayed directly on the balling disc, thus bypassing mixing operation in a blender and P-Kay mixer.

Because of the presence of coke breeze in the filtercake (1.09%), peat moss addition was lowered to 0.5% (dry) with 0.1% NaOH. A low drop number was obtained and green ball moisture was only at 8.5% level.

6. In spite the fact that good green ball quality was achieved with 0.09% Alchem 8C26, the pot grate firing did not show satisfactory results for acid pellets.

   Further testwork with Alchem as a binder for acid pellets was not carried out due to time schedule and budget constraints.

7. Similarly for peat moss, the pot grate results showed poor physical quality. This can be attributed to excessive internal heat (0.5% peat plus 1.09% coke). Because the filtercake without coke breeze was not available, the optimization of peat moss as a potential binder for acid pellets was not continued.

8. The remainder of the pot grate testwork on potential binders was conducted on fluxed pellets. The fluxed pellet chemistry used for these tests was identical to the chemistry of Carol Pellet Plant production planned for this summer.

   The pot grate results on fluxed pellets showed the following:

   a) In spite of slightly lower green ball properties with 0.09% Alchem 8C26, an acceptable physical quality was obtained, (tumble 4.7 and fired compression 255 kg/p). Obviously, these physical properties are slightly lower than for bentonite. On the other hand, very good metallurgical properties were achieved, reducibility 1.33, porosity 33.2, swelling 11.8 and LTD 96.7.

   It should be noted that the green ball moisture for these tests was at 8.5% level.

b) At 0.5% (dry) peat moss with 0.1% NaOH addition for fluxed pellets, green ball moisture was 8.6% and drop number was low. Tumble index of 4.6 and fired compression of 202 kg/p were obtained. Here again, as a result of excessive internal heat (0.5% peat plus 1.09% coke breeze), lower physical quality resulted. In spite of this, good metallurgical quality was obtained. Reducibility 1.36, porosity 30.7, swelling 13.5 and LTD 95.4 were achieved. It appears that lower internal heat (less coke in the pelletizing mix) could improve physical properties of fired pellets.

9. Based on the test results with fluxed pellets, there is a possibility that peat moss could be used as a substitute binder and partial or complete replacement for coke breeze.

10. The test results indicated that both selected potential binders (Alchem and peat moss) may require some bentonite or limestone or dolomite when used for acid pellet production in order to meet overall pellet quality specification.

11. There is an indication that both selected organic binders improve metallurgical properties, while slightly affecting the physical quality of fired pellets.

12. With respect to economical aspect of the two potential binders tested, further testwork is required to find the addition rates and/or the combination of the binders for the production of desired pellet quality, particularly for acid pellets. In other words further testwork is required to redefine technical and economical viability of these two potential binders.

6.0 RECOMMENDATIONS

It is recommended to carry out additional testwork to further evaluate two potential substitute binders, ie. Alchem 8C26 and peat moss. Further testwork should include the laboratory tire balling and pilot plant 1 meter disc balling and pot grate firing to find out the following:

a) Determine optimum addition rates of individual binders for desired pellet quality.

b) Investigate possibility of using the combination of two different binders.

c) Determine optimum balling parameters and addition rates for acceptable pellet quality.

d) Establish an optimum firing cycle for the individual binders and their various combinations.

e) Determine the effect of potential binders on physical and metallurgical quality of pellets.

f) Determine the possibility of using peat moss as a substitute binder for bentonite and the partial or complete substitute for coke breeze.

g) Evaluate the economics of potential substitute binders.

All the above recommended items should be carried out for acid and fluxed pellets. The details of the proposed future testwork are shown in Tables 1 through 5. As can be seen from these tables, coke addition will be in the range from zero to 1.2%. Therefore, filtercake without coke breeze will need to be collected.

However, because of the current flowsheet of the Carol Pellet Plant, this is not possible without shutting down coke addition system for at least two days. Since some other current and future studies will require the filtercake without coke breeze it is recommended to collect 50 to 60 tonnes of this type of filtercake. The second alternative is to separately collect spiral, cone and mag concentrates and coke and carry out grinding, filtering and blending in a pilot plant facilities. The negative aspect of this alternative is the difficulty of producing a representative filtercake mixture.

7.0 TABLES

TABLE NO. 1

PROPOSED POT GRATE PROGRAM - SUBSTITUTE BINDER FOR BENTONITE

TEST NO.	PELLET CHEMISTRY	PELLETIZING MIX - ADDITIVES							FIRING CYCLE							
		BENTONITE	PEAT MOSS	NaOH	ALCHEM 8C26	COKE	DOLOM.	LIME.	G.F.	ΔP	TEMPERATURE PROFILE					
		%	%	%	%	%	%	%	%	W.C.	UDD DDD	PH	F-1	F-2	F-3	AF
1	Acid Pellets	0.8	-	-	-	0.85	-	-	100 (36min)	18(16) 20(18)	500	1400	1950 2300	2350 2300	1900	1600
2	Acid Pellets	0.8	-	-	-	1.00	-	-	100 (110)	18(16) 20(18)	500 500	1400	1950 2300	2350 2150	1900	1600
3	Acid Pellets	0.2	(dry) 0.3	0.1	-	0.55	-	-	100 (110)	18(16) 20(18)	500 500	1400	1950 2300	2350 2300	1900	1600
4	Acid Pellets	0.2	0.3	0.1	-	0.70	-	-	100 (110)	18(16) 20(18)	500 500	1400	1950 2300	2350 2150	1900	1600
5	Acid Pellets	-	0.5	0.1	-	0.35	-	-	100 (110)	18(16) 20(18)	500 500	1400	1950 2300	2350 2300	1900	1600
6	Acid Pellets	-	0.5	0.1	-	0.50	-	-	100 (110)	18(16) 20(18)	500 500	1400	1950 2300	2350 2150	1900	1600
7	Acid Pellets	0.2	1.0	0.10	-	-	-	-	100 (110)	18(16) 20(18)	500 500	1400	1950 2300	2350 2150	1900	1600

TABLE NO. 2

PROPOSED POT GRATE PROGRAM - SUBSTITUTE BINDER FOR BENTONITE

TEST NO.	PELLET CHEMISTRY	PELLETIZING MIX - ADDITIVES							FIRING CYCLE							
		BENTONITE	PEAT MOSS	NaOH	ALCHEM 8C26	COKE	DOLOM.	LIME.	G.F.	ΔP	TEMPERATURE PROFILE					
		%	%	%	%	%	%	%	%	W.C.	UDD DDD	PH	F-1	F-2	F-3	AF
8	Acid Pellets	-	1.0	0.15	-	-	-	-	100 (110)	18(16) 20(18)	500 500	1400	1950 2300	2350 2150	1900	1600
9	Acid Pellets 1% limestone	- 0.2	0.5 0.3	0.1 (0.1)	- -	0.55 0.75	- -	1.0 1.0	100 (110	18(16) 20(18)	500 500	1400	1950 2300	2350 2150	1900	1600
10	Acid Pellets 1% Dolomite	- 0.2	0.5 0.3	0.1 (0.1)	- -	0.55 0.75	1.0 1.0	- -	100 (110)	18(16) 20(18)	500 500	1400	1950 2300	2350 2150	1900	1600
11	Fluxed Pellets CaO/SiO_2=0.9 MgO=1.8%	0.8	-	-	-	1.0	5.78	3.85	100 (110) (90)	20(18) 20(18)	500 500	1300	1900 2370	2370 2250	2100	1600
12	CaO/SiO_2=0.9 MgO=1.8%	0.8	-	-	-	1.2	5.78	3.85	100 (110) (90)	20(18) 20(18)	500 500	1300	1900 2370	2370 2250	2100	1600
13	CaO/SiO_2=0.9 MgO=1.8%	0.2	0.3	0.1	-	0.70	5.78	3.85	100 (110) (90)	20(18) 20(18)	500 500	1300	1900 2370	2370 2250	2100	1600
14	CaO/SiO_2=0.9 MgO=1.8%	0.2	0.3	0.1	-	0.90	5.78	3.85	100 (110) (90)	20(18) 20(18)	500 500	1300	1900 2370	2370 2250	2100	1600

TABLE NO. 3

PROPOSED POT GRATE PROGRAM - SUBSTITUTE BINDER FOR BENTONITE

TEST NO.	PELLET CHEMISTRY	PELLETIZING MIX - ADDITIVES							FIRING CYCLE							
		BENTONITE	PEAT MOSS	NaOH	ALCHEM 8C26	COKE	DOLOM.	LIME.	G.F.	ΔP	TEMPERATURE PROFILE					
		%	%	%	%	%	%	%	%	W.C.	UDD DDD	PH	F-1	F-2	F-3	AF
15	CaO/SiO_2=0.9 MgO=1.8%	-	0.5	0.1	-	0.50	5.78	3.85	100 (110) (90)	20(18) 20(18)	500 500	1300	1900 2370	2370 2250	2100	1600
16	CaO/Sio_2=0.9 MgO=1.8%	-	0.5	0.1	-	0.70	5.78	3.85	100 (110) (90)	20(18) 20(18)	500 500	1300	1900 2370	2370 2250	2100	1600
				Alternate cycle for Flux with 1.2% internal fuel					100	20(18) 20(18)	500 500	1300	1900 2300	2300 2250	2100	1700
17	Acid Pellets	0.2 0.2			0.1 0.05	1.0 1.0	- -	- -	100 (110)	18(16) 20(18)	500 500	1400	1950 2300	2350 2150	1900	1600
18	Acid Pellets			(0.1)	0.1 0.08 0.10	1.0 1.0	-	-	100 (110)	18(16) 20(18)	500 500	1400	1950 2300	2350 2150	1900	1600
19	Acid Pellets	-	0.3	0.1	0.10	0.70	-	-	100 (110)	18(16) 20(18)	500 500	1400	1950 2300	2350 2150	1900	1600
20	Acid 1% Limestone	0.2	-	-	0.1 (0.05)	1.05	-	1.0	100 (110)	18(16) 20(18)	500 500	1400	1950 2300	2350 2150	1900	1600

TABLE NO. 4

PROPOSED POT GRATE PROGRAM - SUBSTITUTE BINDER FOR BENTONITE

TEST NO.	PELLET CHEMISTRY	PELLETIZING MIX - ADDITIVES							FIRING CYCLE							
		BENTONITE	PEAT MOSS	NaOH	ALCHEM 8C26	COKE	DOLOM.	LIME.	G.F.	ΔP	TEMPERATURE PROFILE					
		%	%	%	%	%	%	%	%	W.C.	UDD DDD	PH	F-1	F-2	F-3	AF
21	Acid 1% Limestone		0.3	0.1	0.1 (0.05)	0.75	-	1.0	100 (110)	18(16) 20(18)	500 500	1400	1950 2300	2350 2150	1900	1600
22	Acid 1% Limestone		-	- 0.1	0.1 0.1	1.05 1.05	-	1.0 1.0	100 (110)	18(16) 20(18)	500 500	1400	1950 2300	2350 2150	1900	1600
23	Acid 1% Dolomite	0.2	-	-	0.1 (0.05)	1.05	1.0	-	100 (110)	18(16) 20(18)	500 500	1400	1950 2300	2350 2150	1900	1600
24	Acid 1% Dolomite	-	0.3	0.1	0.1	0.75	1.0		100 (110)	18(16) 20(18)	500 500	1400	1950 2300	2350 2150	1900	1600
25	Acid 1% Dolomite			0.1	0.1 0.1	1.05 1.05	1.0 1.0		100 (110)	18(16) 20(18)	500 500	1400	1950 2300	2350 2150	1900	1600
26	Fluxed CaO/SiO_2=0.9 MgO=1.8%	0.2	-	-	0.1 (0.05)	1.0	5.78	3.85	100 (110)	20(18) 20(18)	500 500	1300	1900 2370	2370 2250	2100	1600

TABLE NO. 5

PROPOSED POT GRATE PROGRAM - SUBSTITUTE BINDER FOR BENTONITE

TEST NO.	PELLET CHEMISTRY	PELLETIZING MIX - ADDITIVES							FIRING CYCLE							
		BENTONITE	PEAT MOSS	NaOH	ALCHEM 8C26	COKE	DOLOM.	LIME.	G.F.	ΔP	TEMPERATURE PROFILE					
		%	%	%	%	%	%	%	%	W.C.	UDD DDD	PH	F-1	F-2	F-3	AF
27	Fluxed CaO/SiO_2=0.9 MgO=1.8%			0.1	0.1 0.1	1.0 1.0	5.78 5.78	3.85 3.85	100 (110)	20(18) 20(18)	500 500	1300	1900 2370	2370 2250	2100	1600
28	Fluxed CaO/SiO_2=0.9 MgO=1.8%			0.1	0.1 0.1	1.2 1.2	5.78 5.78	3.85 3.85	100 (110)	20(18) 20(18)	500 500	1300	1900 2370	2370 2250	2100	1600
29	Fluxed CaO/SiO_2=0.9 MgO=1.8%	-	0.3	0.1	0.1 (0.05)	0.70	5.78	3.85	100 (110)	20(18) 20(18)	500 500	1300	1900 2370	2370 2250	2100	1600
30	Fluxed CaO/SiO_2=0.9 MgO=1.8%	-	0.3	0.1	0.1 (0.05)	0.90	5.78	3.85	100 (110)	20(18) 20(18)	500 500	1300	1900 2370	2370 2250	2100	1600

NOTE:

- Determine addition rates for additives to produce acceptable green ball quality using tire balling
- Allow 2 pot grate tests for each optimum pot (pellet quality)
- Metallurgical properties for each optimum pot (pellet quality)

NOTE: Cont'd.

NOTE: Cont'd.

- Figures in brackets are alternates
- Percentages for dolomite and limestone for fluxed pellets are approximate values, pellet chemistry is to be used for pelletizing mix composition
- Only one alternate firing cycle is shown. Depending on pellet bed inspection after the pot grate firing and physical quality of pellets additional alternate cycles could be used. (Grate factor, ΔP, Temperature profile and bed depth).

8.0 APPENDICES

APPENDIX I

REPORT ON RESULTS OF TEST - PHASE I

IRON ORE COMPANY OF CANADA

OFFICES - BUREAUX
SEPT-ILES, QUEBEC
MONTREAL, QUEBEC
SCHEFFERVILLE, QUEBEC
LABRADOR CITY, NEWFOUNDLAND - TERRE-NEUVE
ST. JOHN'S, NEWFOUNDLAND - TERRE-NEUVE

Proposal DSS No. 03SQ.23440-4-9316

DEVELOPMENT OF A TECHNICALLY AND ECONOMICALLY ACCEPTABLE SUBSTITUTE BINDER FOR BENTONITE FOR USE WITH CAROL LAKE CONCENTRATE

REPORT ON RESULTS OF TEST PHASE I

Submitted to

DEPARTMENT OF SUPPLY AND SERVICES CANADA

March 29, 1985

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1.0 SUMMARY

Testwork was carried out at the Iron Ore Company of Canada's Carol Pellet Plant to study the possibility of using Peridur, a cellulose-based polymer, as a binder for the pelletizing of iron ores. The work outlined in this report is the first phase of the test program and is primarily concerned with the formation of green balls.

Several tests were conducted from February 19 to March 2, 1985, during which time Peridur was continuously added over extended periods of up to 8 consecutive shifts. The addition rate was varied from 0.45 kg/t, which is equivalent in cost to the current bentonite consumption, to 1.12 kg/t.

The balling operation went smoothly when Peridur was used. No major material handling problem or operational upset was experienced.

On the other hand, in the above-mentioned addition range, the properties of Peridur-based green balls were generally poorer than the material produced with bentonite. It is not certain, however, whether acceptable quality of fired pellets can still be obtained with these inferior green ball properties.

Therefore, pot grate testwork is recommended to determine whether acceptable quality pellets can be produced from Peridur-based green balls.

2.0 INTRODUCTION

A two phase test program has been initiated by the Iron Ore Company of Canada to investigate the feasibility of using an organic binder as a substitute for bentonite in its pelletizing operation.

The project is co-funded by the Department of Supply and Services Canada. Refer to Reference No. 1.

The following report summarizes the findings of the first phase of the program. This phase studied the effects of Peridur, the most promising product among the potential organic pellet binders identified to date, on the balling unit operation.

3.0 OBJECTIVES OF TEST PHASE I

A substitute for bentonite as pellet binder should meet the following requirements:

a) Simple and trouble-free application under plant conditions.

b) Acceptable green balls properties.

c) Consumption rate corresponding to same or lower binder unit cost as compared to bentonite.

d) Same or superior physical and metallurgical qualities of fired pellets.

The primary objective of the test Phase I was to investigate the suitability of Peridur with respect to points a) to c). Point d) would be studied in detail in Phase II.

Specifically, the program for test Phase I was to include the following items:

1. Balling tests on one of the plant balling modules at different Peridur addition levels.
2. Preliminary pellet quality tests
3. Testing of precision feeders

The balling tests were to be conducted at the Carol Pellet Plant located in Labrador City, Newfoundland.

Pellet quality tests were to be done at the Carol Pellet Plant and a contractor's laboratory.

The testing of precision feeders was to be performed by a potential equipment supplier(s).

4.0 DESCRIPTION OF TEST MATERIALS, EQUIPMENT AND PROCEDURES

4.1 Materials

Peridur

Peridur is a free-flowing, fine powder with an appearance similar to non-dairy cream powder. According to its supplier, the ENKA Industrial Colloids of Arnhem, Holland, it is a non-toxic, biologically degradable cellulose-based polymer modified with various chemical compounds.

The main advantage of Peridur over bentonite as a binder is its organic nature. It was reported that not only a dilution of the chemical composition of fired pellets can be prevented, but also improvements of porosity and reducibility of pellets can be achieved. Other advantages include lower storage and transportation cost.

More descriptive details of the product and its effects as an iron ore pellet binder can be found in the supplier's literature and the articles referred therein (see Appendix 11).

For the test Phase I, a shipment of 10 t was ordered. The material arrived in "Holbins" or cardboard containers of 500 kg net weight each.

Iron Ore Filter Cake

The typical Carol filter cake contains approximately 8.8% moisture and has the following analysis (dry basis)

Fe	66.2%
SiO_2	4.5%
Magnetite	35.0%
+ 0.147 MM	1.0%
- 0.044 MM	65-70%
Blaine Surface Area	1600 cm^2/g

4.2 Test Equipment

The balling tests were conducted on module 6 of the Carol Pellet Plant. This module is typical of the 26 balling circuits of the plant with respect to equipment configurations, mechanical conditions and operating parameters.

The test arrangements are shown in Appendix No. 5.

The iron ore concentrate received from the regrind circuit is filtered in a 2.06 m Eimco disc filter equipped with 8 discs of 20 sectors per disc for a total area of ~~2,256~~ 256 m^2 ~~each~~. Vacuum in the range of 74.5 to 84.7 kilopascals is applied to the filter to produce filter cake with a moisture content of approximately 8.8%. The normal operating range of the filter feed rate is 55 to 65 tph per unit.

The balling drum is 3.05 m in diameter by 9.14 m in length sloped at 8 degrees. It is driven at a fixed speed of 6 rpm by a 35 HP motor. The rubber drum liner is of special design which allows a satisfactory drum operation without cutter bars.

The drum is fed with the mixture of filter cake material and binder. When bentonite is used, the addition to filter cake is done using a volumetric feeder.

The bentonite feeder speed is adjusted automatically based on the filter cake table feeder speed, which is in proportion to the filter cake tonnage.

When Peridur was added, a loss-in-weight feeder system was used. This unit was specifically designed by the Peridur supplier to obtain precise measurement of the addition dosage. As shown in Appendix No. 6, the system consisted of the Holbin discharge unit, the K-tron loss-in-weight feeder and the transport auger. The Holbin discharge unit functions as a refill device for the feeder. The loss-in-weight feeder is equipped with an electronic control unit which adjusts the material discharge weight with the filter cake tonnage based on the preset addition rate. The total height of the system including the Holbin is approximately 4.6 meters.

The mixing of binder with the moist filter cake is accomplished by a Pekay belt mixing system.

The green balls discharged from the drum are classified by a roller screen to obtain "on-size" balls of 9.5 to 12.5 mm diameter. The roller screen is 1.83 m wide by 5.18 m long with 48 rollers sloped at 13.5 degrees.

The oversized balls are shredded, combined with undersize balls and returned to the balling drum as seeds. The on-size product is conveyed and fed to the indurating machine No. 2 together with the green balls from modules No. 5, 7 and 8.

4.3 Test Procedures

To obtain a fair comparison to bentonite, the test on Peridur was monitored carefully to ensure that the process conditions of the test circuit did not differ significantly from the other modules and from the normal operating conditions of the plant.

Following the initial trials of shorter durations, Peridur was used to completely replace bentonite as a binder on module 6 for a period of 8 consecutive shifts. During this period, the rate of addition was adjusted from a low level of 0.45 to a high level of 1.12 kg per ton of iron ore filter cake (wet basis). Each level was maintained for a duration of 4 to 24 hours to allow detailed evaluation.

For each test, the following data was recorded:

- Peridur Addition Rate
- Module Feed Tonnage
- Filter Cake Moisture
- Green ball properties (drop index, wet and dry compression)
- Size distribution of final green balls

Samples of green balls were taken every hour for moisture and drop tests, every two hours for wet and dry compression, and every four hours for size consist determination.

Attempts were also made to run basket tests to obtain preliminary indications on the physical and metallurgical properties of Peridur-based fired pellets. However, due to the inconsistency of the test results, no detailed evaluation was carried out.

5.0 TEST RESULTS

5.1 Results of Balling Operation with Peridur

The balling tests indicated the following:

a) The handling of Peridur presented no major problem. The use of the Holbins did require some attention. However, this type of container would not be used in a routine operation.

b) The switching from bentonite to Peridur could be done swiftly. No evidence of circuit upsets could be observed. Due to the relatively high recirculating load of the drum circuit, the typical appearance of Peridur-based green balls (wet, shiny and reddish surfaces) could be seen only 5 to 7 minutes after the switch to the organic binder was made.

c) No excessive surging or increase in recirculating load was seen as the fresh feed rate of the module was varied within the range of 55-65 tonnes per hour (wet basis).

d) No excessive build-up of material on drum liner, roller screen, skirtings and conveyor transfer points could be noted.

From an operational viewpoint, the use of Peridur was satisfactory at the normal filter cake moisture of 8.7 - 9.0%.

5.2 Properties of Green Balls

The properties of green balls formed at different levels of Peridur addition are summarized in Appendix Nos. 1 and 2.

The following trends can be noted:

a) Within the consumption range of 0.45 to 1.12 kilogram per tonne of balling feed, the qualities of Peridur-based green balls are inferior to the bentonite-based product.

b) The drop index increased with the addition level of Peridur. Refer to Appendix 3. The normal standard for bentonite green balls of 8 drops could be obtained only at an addition of 1.12 kg/t.

c) The wet compression strength did not seem to be affected by the Peridur addition as it remained within the narrow range of 0.8 to 1.0 kg.

d) The dry compression increased with the Peridur dosage. Refer to Appendix 4. At 1.12 kg/t a value of 3.0 kg was obtained. At the normal bentonite consumption (8.5 kg/t), the typical dry compression of Carol green balls is 6.8 kg.

e) The surface of the Peridur-based green balls appeared extremely watery, especially at a low binder rate. Evidence of fines and seeds sticking to the on-size balls could be clearly seen on the drum discharge product (roller screen feed). The screened product, however, exhibited a normal size consist. Refer to Appendix 2.

In general, it can be stated that at an addition rate near the current economical level (approximately 0.45 kg/t), Peridur does not meet the standards set for bentonite.

It is, however, also reasonable to state that a full assessment cannot be made until the physical and metallurgical properties of fired pellets are evaluated.

Due to the difficulties associated with the making of a small quantity of fired pellets under specific and controlled conditions in a production indurating machine, and because of the limited validity of a basket test, reliable data on the fired pellet quality could not be obtained in Phase I.

5.3 Results of Feeder Test

Due to the high unit cost of Peridur, its variable bulk density, as well as the expected low addition dosage (0.5 to 1 kilogram per minute to each module), the volumetric bentonite feeders are not suitable for the addition of the organic binder.

The supplier of Peridur recommends a loss-in-weight feeder of similar type as the test unit installed on module 6. This equipment provides excellent accuracies (less than 0.5% minute-to-minute at 2 sigma). However, due to the high cost and fragility of the unit, it appears desirable to find a more cost-effective feeder capable of withstanding the typical plant conditions in terms of humidity, vibration and dust.

After a survey of potential feeder suppliers, the Peacock Company of Montreal, who represent Vibra Screw Inc. of Totawa, N.J., was chosen to test Peridur for feeder selection.

A 500 kg sample of Peridur was sent to Vibra Screw research facility for material characteristics analysis.

The test results can be found in Appendix No. 8.

Peridur was classified as a non-pressure sensitive material consisting of very fine fibers which tend to mat and interlock together.

Based on these test data, a two component system was recommended for the Peridur application. The system would consist of a bin vibrator, which would be installed at the bottom of the binder feed bin, and a gravimetric feeder model Vibra Metric 2-25. Refer to Appendix 9 for a detailed description of the recommended equipment.

A rental arrangement was proposed by Peacock to supply four systems for Phase IIb of the Peridur test program. Refer to Appendix 10.

6.0 RECOMMENDATIONS FOR FUTURE WORK

As described earlier, although the application of Peridur was trouble-free from the operational viewpoint, the metallurgical results obtained were less encouraging than anticipated. The critical question is whether the relatively poor green ball characteristics, as measured by standards set for bentonite-based product, are adequate for the indurating machines to produce pellets of acceptable quality.

This question could not be positively answered by the work of Phase I.

In view of the numerous potential benefits of the organic binder, it is recommended that Phase II of the test program be carried out.

In this phase, pot grate testwork would be performed under specified process conditions to determine whether satisfactory quality of the final pellets can be obtained with Peridur as a binder.

Only a positive result of Phase II would justify the testing on an entire production line.

An outline of the tentative test program for the proposed pot grate work is shown in Appendix No. 12.

7.0 REVIEW OF PROJECT SCHEDULE

Appendix 7 shows the updated schedule for Phase II of the test project. The completion date for this phase is now August 19, 1985. This is an 8 week delay of the original schedule stated in the proposal to the Department of Supply and Services Canada (Reference No. 1). The delay is caused primarily by the longer delivery of feeders and by the bidding selection to determine the most suitable laboratory to conduct the pot grate tests.

REFERENCES

1. Proposal DSS No. 03SQ.23440-4-93-16 "Development of a Technically and Economically Acceptable Substitute Binder for Bentonite for Use with Carol Lake Concentrate" dated February 1985, submitted by the Iron Ore Company of Canada.

APPENDIX 1

TEST RESULTS: GREEN BALL PROPERTIES

CR - PELLET PLANT

RESULTS OF BALLING TESTS ON PERIDUR

GREEN BALL PROPERTIES

Date	PERIDUR		FILTER CAKE		GREEN BALLS	CHARACTERISTICS	
	Addition (kg/t)	%Mc	Blaine	Rate (tph)	Drop	Wet Comp. (kg)	Dry Comp. (kg)
03/01-02 a.m.	0.45	8.6	1588	58.5	5.1	0.8	0.7
02/21 D/S a.m.	0.55	8.6	1605	58.6	6.2	0.9	1.2
02/21 N/S	0.58	8.8	1615	59.8	7.1	0.8	1.4
02/20 D/S p.m.	0.60	9.0	1720	54.1	7.2	0.8	1.5
02/20 A/S	0.64	8.9	1705	58.6	6.3	0.8	1.3
02/21 A/S	0.72	8.8	1635	59.3	6.8	0.9	1.1
02/22 D/S a.m.	0.75	9.0	1580	59.0	8.2	0.9	1.4
02/20 N/S	0.80	8.9	1625	58.8	7.7	0.9	1.9
02/20 D/S a.m.	0.80	8.7	1720	60.3	7.4	0.8	1.5
02/19 D/S	0.86	8.7	1670	57.8	7.2	1.0	1.9
02/19 A/S	0.86	8.9	1700	57.8	7.0	1.0	1.5
02/27 D/S	1.12	8.6	1550	58.0	8.0	0.9	3.0
Typical Values Obtained w. BENTONITE	8.50	8.7	1600	58.0	9.0	0.9	6.8

APPENDIX 2

TEST RESULTS: GREEN BALL SIZE CONSIST

CR - PELLET PLANT

RESULTS OF BALLING TESTS ON PERIDUR

GREEN BALL SIZE CONSIST

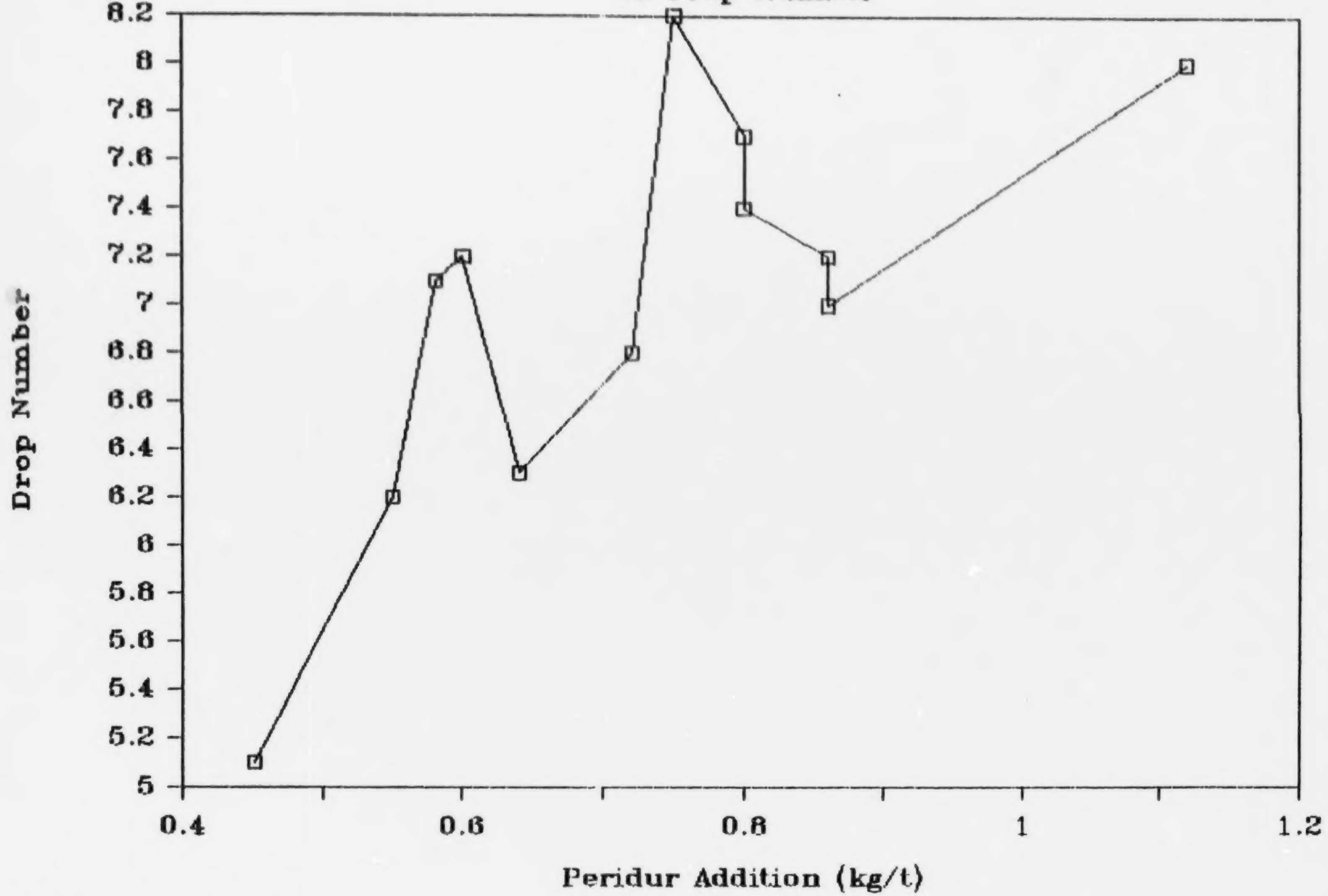
Date	PERIDUR Addition (kg/t)	FILTER CAKE			GREEN BALL SIZE CONSIST (% Wt)					
		%Mc	Blaine	Rate (tph)	+15.9mm	+12.7mm	+10mm	+9.5mm	-9.5mm	TOTAL
03/01-02 a.m.	0.45	8.6	1588	58.5	0.0	8.4	79.0	5.4	7.2	100.0
02/21 D/S a.m.	0.55	8.6	1605	58.6	1.1	13.4	71.8	5.9	7.8	100.0
02/21 N/S	0.58	8.8	1615	59.8	0.5	8.9	75.1	4.5	11	100.0
02/20 D/S p.m.	0.60	9.0	1720	54.1	0.6	10.8	75.2	4.9	8.5	100.0
02/20 A/S	0.64	8.9	1705	58.6	0.5	8.9	75.1	4.5	11.0	100.0
02/21 A/S	0.72	8.8	1635	59.3	0.5	11.3	70.7	5.8	11.7	100.0
02/22 D/S a.m.	0.75	9.0	1580	59.0	2.7	7.8	65.0	6.2	18.3	100.0
02/20 N/S	0.80	8.9	1625	58.8	1.3	7.6	72.2	3.9	15.0	100.0
02/20 D/S a.m.	0.80	8.7	1720	60.3	0.3	9.6	73.4	6.0	10.7	100.0
02/19 D/S	0.86	8.7	1670	57.8	0.5	9.7	66.8	6.0	17.0	100.0
02/19 A/S	0.86	8.9	1700	57.8	1.1	8.7	75.1	4.7	10.4	100.0
02/27 D/S	1.12	8.6	1550	58.0	0.2	7.0	72.8	6.3	13.7	100.0
Typical Values Obtained w. BENTONITE	8.50	8.7	1600	58.0	1.0	14.0	70.0	5.0	10.0	100.0

APPENDIX 3

EFFECTS OF PERIDUR ADDITION ON DROP INDEX

Effect of Peridur Addition

On Drop Number

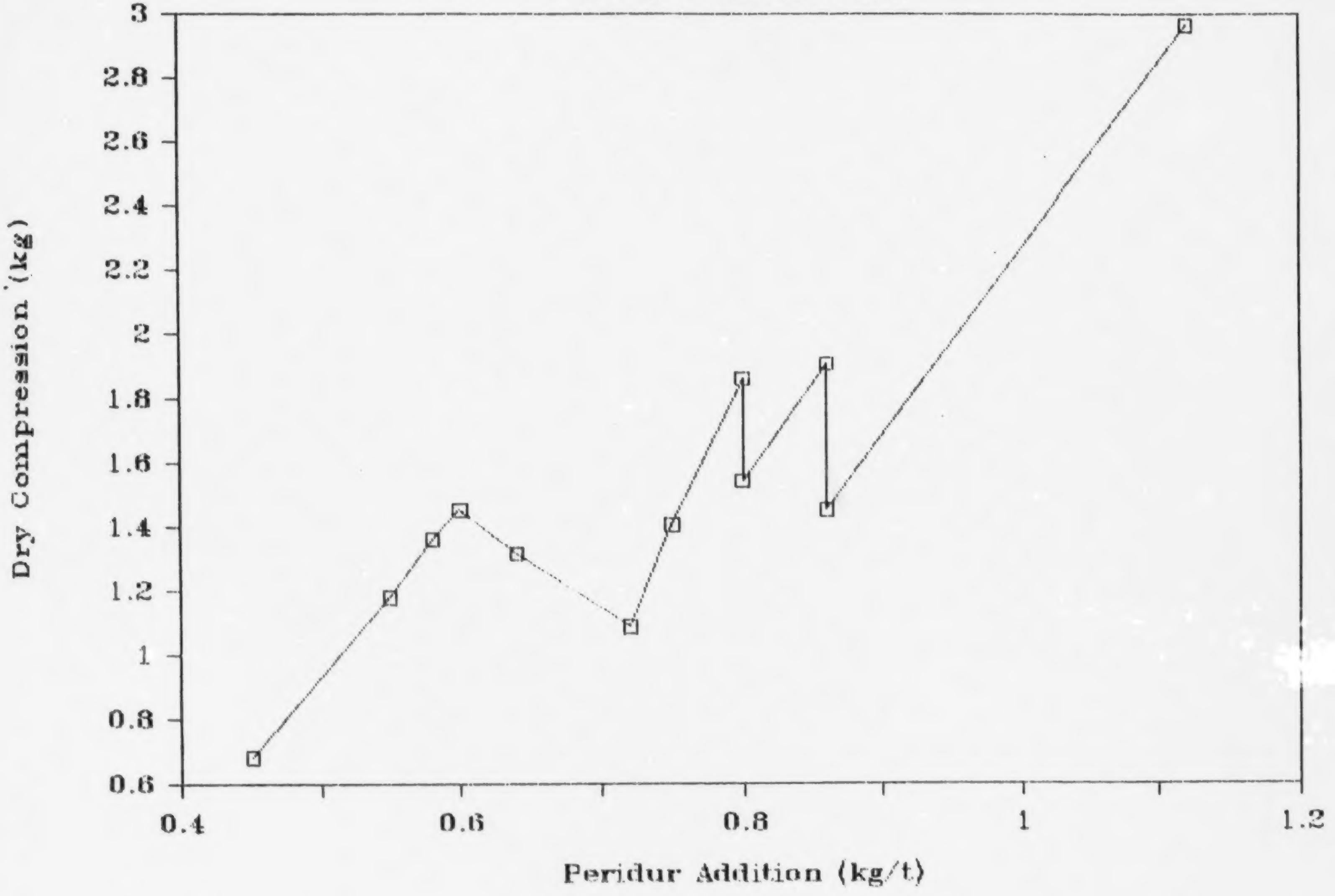


APPENDIX 4

EFFECTS OF PERIDUR ADDITION ON DRY COMPRESSION

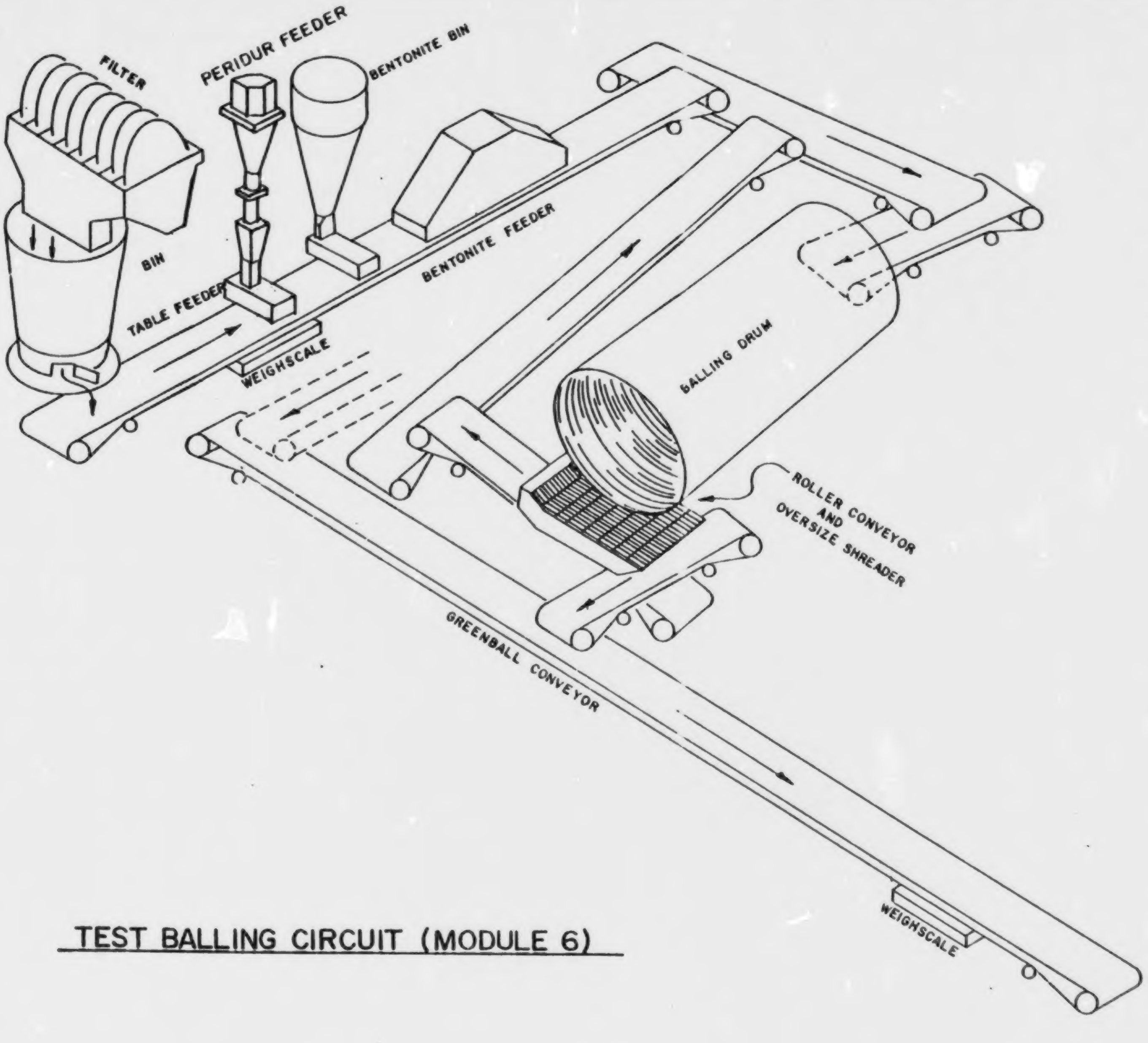
EFFECT OF PERIDUR ADDITION

ON DRY COMPRESSION



APPENDIX 5

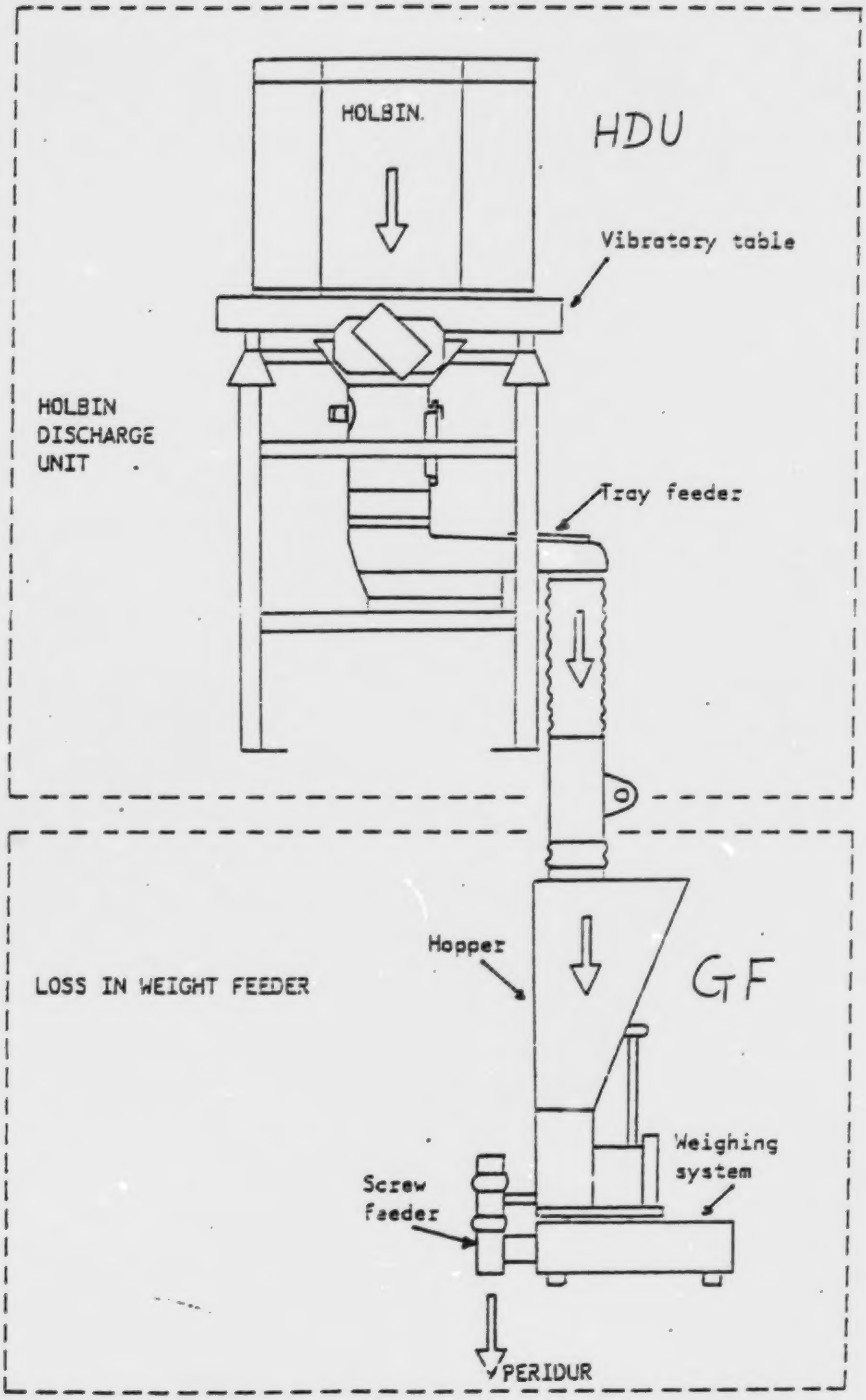
TEST CIRCUIT ARRANGEMENTS


FILTER
PERIDUR FEEDER
BENTONITE BIN
BIN
TABLE FEEDER
WEIGHSCALE
BENTONITE FEEDER
BALLING DRUM
ROLLER CONVEYOR
AND
OVERSIZE SHREADER
GREENBALL CONVEYOR
WEIGHSCALE

TEST BALLING CIRCUIT (MODULE 6)

APPENDIX 6

PERIDUR FEEDER SYSTEM

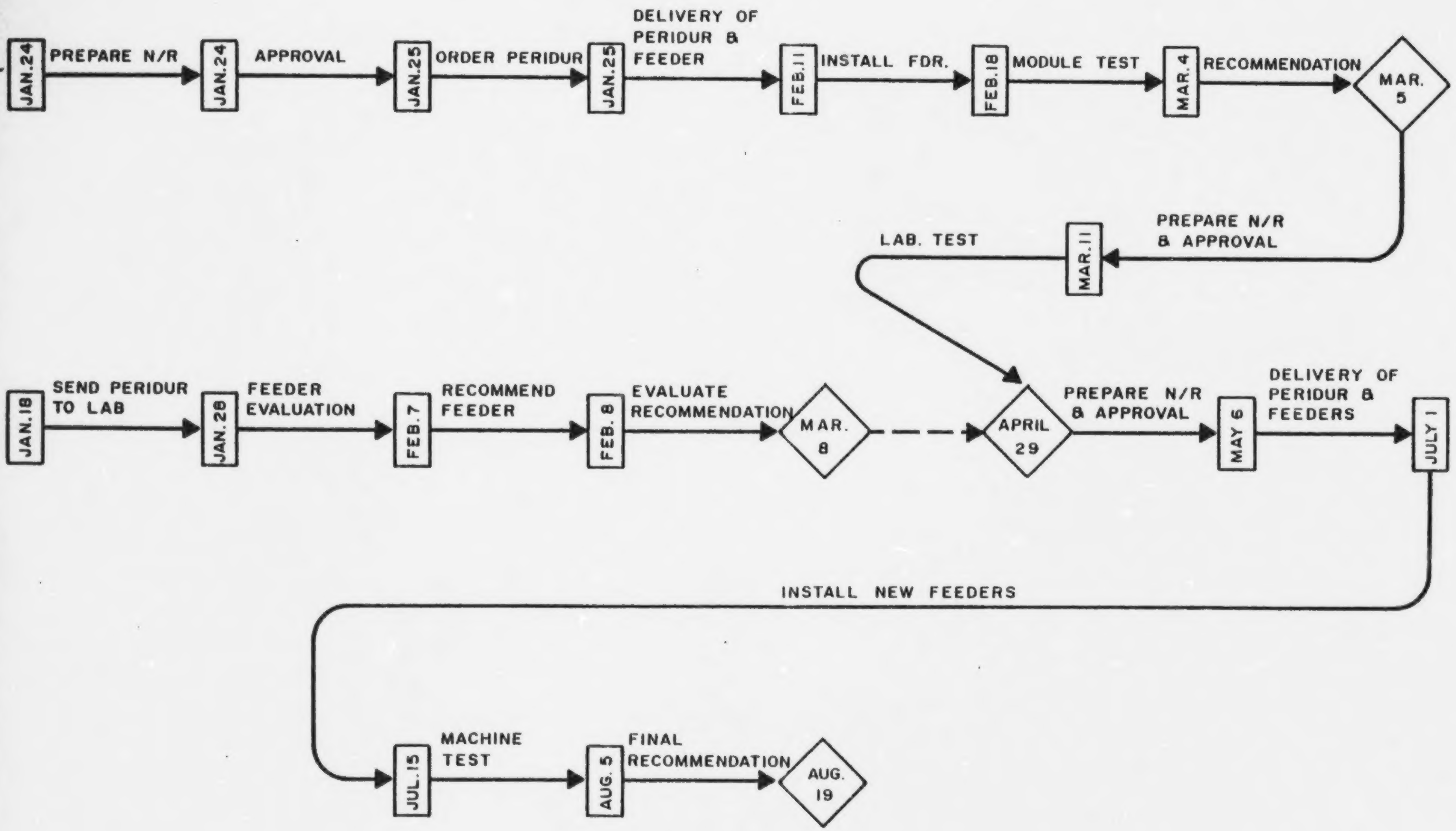

HOLBIN.
HDU
Vibratory table
HOLBIN
DISCHARGE
UNIT
Tray feeder
Hopper
LOSS IN WEIGHT FEEDER
GF
Weighing
system
Screw
feeder
PERIDUR

Peridur dosing system

APPENDIX 7

TEST SCHEDULE

REDUCE BINDER COST C.P.M.


JAN.24
PREPARE N/R
JAN.24
APPROVAL
JAN.25
ORDER PERIDUR
JAN.25
DELIVERY OF PERIDUR & FEEDER
FEB.11
INSTALL FDR.
FEB.18
MODULE TEST
MAR.4
RECOMMENDATION
MAR. 5
PREPARE N/R & APPROVAL
MAR.11
LAB. TEST
JAN.18
SEND PERIDUR TO LAB
JAN.28
FEEDER EVALUATION
FEB.7
RECOMMEND FEEDER
FEB. 8
EVALUATE RECOMMENDATION
MAR. 8
APRIL 29
PREPARE N/R & APPROVAL
MAY 6
DELIVERY OF PERIDUR & FEEDERS
JULY 1
INSTALL NEW FEEDERS
JUL.15
MACHINE TEST
AUG. 5
FINAL RECOMMENDATION
AUG. 19

FEB. 4, 1985
MAR. 4, 1985
MAR. 28, 1985

APPENDIX 8

RESULTS OF FEEDER TESTS

PEACOCK
INC
(514) 366-5900
C.P. 1040, STATION A MONTRÉAL, QUÉBEC H3C 2X5
TÉLEX—055-66221

March 11, 1985

IRON ORE OF CANADA
P.O. Box 1000
Labrador City, Newfoundland
A2V 2L8

Attention: Mr. Amh Mai, Project Eng.

Subject: 'Peridur'

Gentlemen:

Further to our recent discussions, please find attached the 'material characteristic' report done by Vibra-Screw Inc.

It is from this report and actual equipment testing that we were able to recommend the correct equipment for your application.

Looking forward to working with your on this project, we remain.

Yours truly,

D Wallace

Douglas Wallace

DW/11
Encl.: File report P-85-501 (2)

SPECIALISTS IN THE PRECISION PROCESSING OF DRY MATERIALS
OFFICES THROUGHOUT THE U.S., CANADA, MEXICO, S.A., EUROPE, ASIA, AFRICA, AUSTRALIA AND NEW ZEALAND

Vibra Screw. Incorporated
755 UNION BOULEVARD, P.O. BOX 229, TOTOWA, N.J. 07511
(201) 256-7410 TELEX: 685-3382

MATERIAL CHARACTERISTICS

LAB NO.: 8109 FILE REF. NO.: P-85-501 DATE: 2/6/85

CUSTOMER: I.O.C. (PEACOCK)

MATERIAL: PERIDUR

1) BULK DENSITY (DYNAMIC)	28.9 LBS./CU.FT.
2) MATERIAL CLASSIFICATION	CLASS III
3) MOISTURE CONTENT	NIL
4) ANGLE OF SLIDE	37 DEGREES
5) PRESSURE SENSITIVITY	NON PRESSURE SENSITIVE
6) PARTICLE SIZE ANALYSIS	THE AVERAGE PARTICLE SIZE IS -200 MESH

SPECIAL NOTES:

AERATED BULK DENSITY - 25.8 LBS./CU.FT.
PACKED BULK DENSITY - 36.4 LBS./CU.FT.
COMPRESSIBILITY - 29 %

THIS MATERIAL CONSISTS OF VERY FINE STRANDS WHICH TEND TO MAT AND INTERLOCK TOGETHER. THE MATERIAL CAN BECOME VERY FLUIDIZABLE WHEN IT IS AERATED.

TESTED BY: AAH

VIBRA SCREW EQUIPMENT IS PROTECTED BY U.S. AND FOREIGN PATENTS ISSUED AND PENDING
U.S. PATENT NOS.: 3151782, D-202088, [illegible], 3261508, 3272024, 3277732, 3278080, 3287300
3297304, 3344293, [illegible], 3411675, [illegible], 3652247, 3773231, [illegible], [illegible]

IRON LAB

PEACOCK MTL

M748 FEB 28/85 ATT MR MAI
REF OUR QUOTE M85-978- VS
AS PER YOUR REQUEST WE ARE PLEASED TO SUBMIT OUR RECOMMENDATIONS
AND QUOTATION FOR VIBRA SCREW EQUIPMENT TO FEED ''PERIDUR''.
OUR PROPOSAL COVERS THE OUTRIGHT PURCHASE AND ALTERNATIVELY RENTAL
WITH OPTION TO PURCHASE.
PROPOSAL NO. 1 OUTRIGHT PURCHASE
ITEM A
FOUR ONLY 4 FT BIN ACTIVATORS OF CARBON STEEL CONSTRUCTION
PRICE 5812.00 DLRS EA NET- FIRM FOR 6 MONTHS- CANADIAN FUNDS.
DLVY 6-8 WEEKS.
ITEM B
FOUR ONLY VIBRA METRIC FEEDERS MODEL 1-25
PRICE 26,238.00 DLRS EA NET- CDN FUNDS, FIRM FOR 6 MONTHS
DLVY 6-8 WEEKS.
PROPOSAL NO.2 PURCHASE/ RENTAL
OUTRIGHT PURCHASE OF ITEM 'A' FOR PRICES STATED THEREIN AND RENTAL
OF ITEM ' B', AT A COST OF 1333.00 DLRS PER UNIT PER MONTH,
FOR A MAX OF SIX MONTHS, WITH OPTION TO PURCHASE WITH FULL RENTAL
COST CREDITED AGAINST EVENTUAL PURCHASE.

PLS NOTE THAT BIN ACTIVATORS ARE OF CDN MANUFACTURE AND THEREFORE
QUOTED FIRM FOR 6 MONTHS, WHEREAS VIBRA METRIC FEEDERS ARE OF
U.S.A. MANUFACTURE. THEREFORE PRICES QUOTED HEREIN FOR PURCHASE
AND RENTAL ARE CDN FUNDS BASED ON CURRENT EXCHANGE RATE OF 1.41
HOWEVER PRICING WUD BE IN ACCORDANCE WITH EXCHANGE RATE AT TIME
OF INVOICING, WHICH WE HOPE WILL BE BENEFICIAL TO YOU.

ALL EQUIPMENT QUOTED HEREIN WHETHER RENTED OR PURCHASED IS GUARANTEED TO PERFORM IN THE SERVICE FOR WHICH IT IS SOLD. SHOULD
IT NOT, IT WILL BE FIXED AT OUR EXPENSE OR MAY BE RETURNED
LESS SHIPPING CHARGES.
REGARDS
A VANDETTE
PEACOCK MTL
TLX 055-66221

IRON LAB

APPENDIX 9

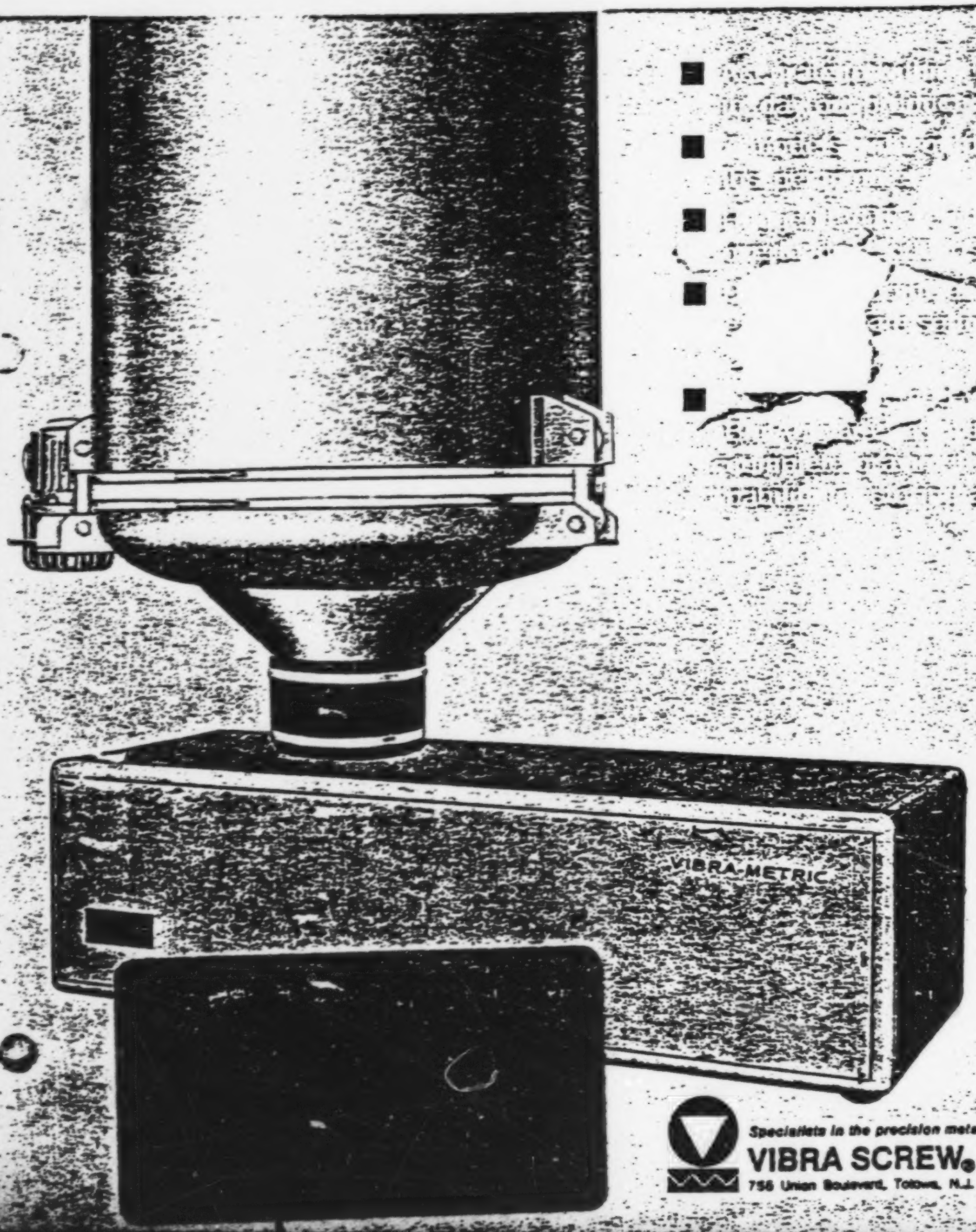
INFORMATION ON FEEDER EQUIPMENT

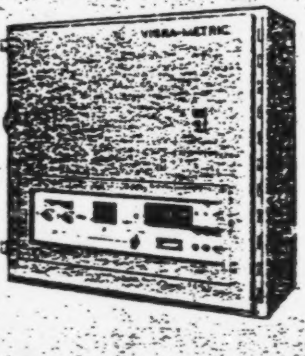
VIBRA METRIC®

Weigh Belt Feeder

rugged, consistently accurate production gravimetric feeder

- [illegible]
- [illegible]
- [illegible]
- [illegible]
- [illegible]



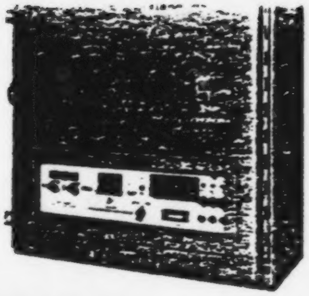


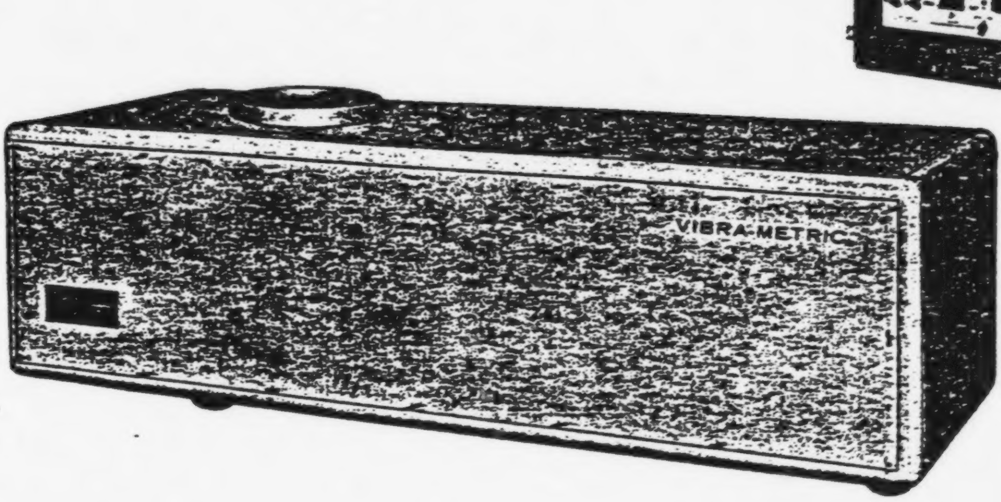
Specialists in the precision metering and hoppering of dry materials.

VIBRA SCREW® INCORPORATED

756 Union Boulevard, Totowa, N.J. 07511 • (201)256-7410 • Telex No. 130-448

VIBRA-METRIC
Weigh Belt Feeder





The Vibra-Metric Weigh Belt Feeder is a rugged gravimetric feeder that is consistently accurate to within ¼ % to ½ % of set rate, [illegible]te-minute, at 2 sigma, for most materials. Co[illegible] ake the punishment of day-in, day-out p[illegible] virtually any environment, it has pr[illegible] curacy, operational stability and deper[illegible] wide range of process applications.

d. 0 to 130
e. Chain dr
VI. FLEXURES
Two-In

Accurate Weighing

Material is fed to the continuous weigh belt by a patented vibrating nozzle with an adjustable gate. The complete belt assembly, as well as the material on it, are weighed to *eliminate* errors due to variations in belt tension. The fulcrum is located directly under the infeed point, eliminating errors due to the force of the material discharging onto the belt. In addition, the input end is supported by Inconel "X" flexures, providing a sturdy pivot that can withstand accidental overloads or shock loading, yet is highly sensitive to the slightest weight change on the belt.

Actual weighing is done by a temperature compensated Linear Voltage Differential Transformer (LVDT) located at the discharge end of the belt. This unit can withstand overloads of 500 lbs. or more without damage. If there is a difference between the preset feed rate and the delivered feed rate, an equalizer circuit provides instantaneous correction commands to the belt drive.

Control

A sophisticated digital setpoint, digital readout controller provides easier, more accurate setting, monitoring and calibration. The controller provides direct readout of the feed rate in a pounds per minute display, eliminating errors due to parallax and interpretation. The digital setpoint provides easier, more accurate setting and repeatability. BCD output is computer compatible with no convertor required.

The control unit may be rack mounted or remotely located at distances as great as 100 feet from the Vibra-Metric Feeder with no modification. NEMA enclosures are provided when the controller is in the process environment.

Capacities From 1 To 700 Pounds/Minute

Seven standard models of the Vibra-Metric Weigh Belt Feeder are available with standard capacities of 1 to 10, 2.5 to 25, 5 to 50, 10 to 100, 20 to 200, 35 to 350 and 70 to 700 pounds per minute.

Three belt sizes are available, 12" wide for production rates to 200 pounds per minute and 20" and 24" wide where required for higher rates. Special construction is available to meet the most demanding sanitary codes.

Control Options

In addition to digital readout of the feed rate, an optional totalizer, which logs the amount of material crossing the weigh belt from startup to shut down and provides a digital readout of the amount, is also available. Inventory records may be logged from this unit for production control, material reordering or supply hopper recharging. A pre-set totalizer, for selecting desired batch weights, is also available.

Other optional features include output signals for remote control of auxiliary equipment, remote readout (charts or digital meters), high and low deviation alarms and automatic zero control.

The Vibra-Metric Meter

Where instantaneous accuracy is not critical but total batch accuracy or record keeping is required, the Vibra-Metric Meter is often suitable. This is basically the same system as the Vibra-Metric Feeder except that the feedback control loop is eliminated.

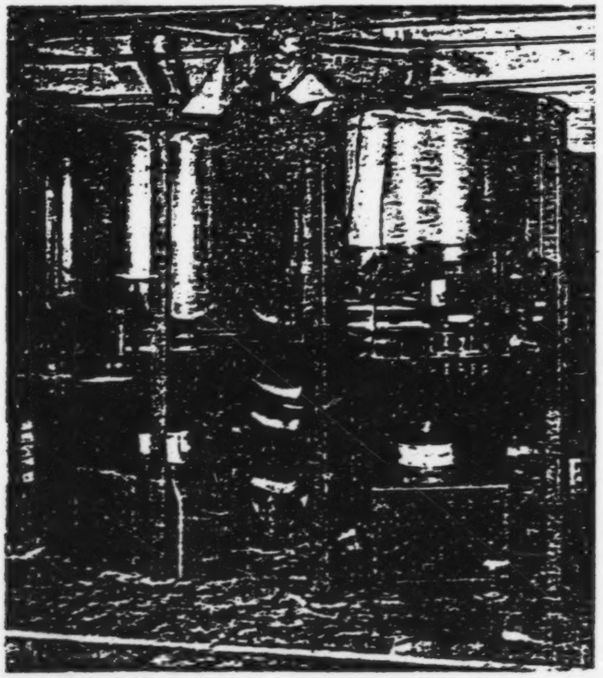
Complete Gravimetric Hoppering/Feeding Systems

In combination with a Vibra Screw Bin Activator, Live Bottom Bin or Live Bin as a pre-feeder, the Vibra-Metric provides a complete gravimetric feeding system for storing and feeding.

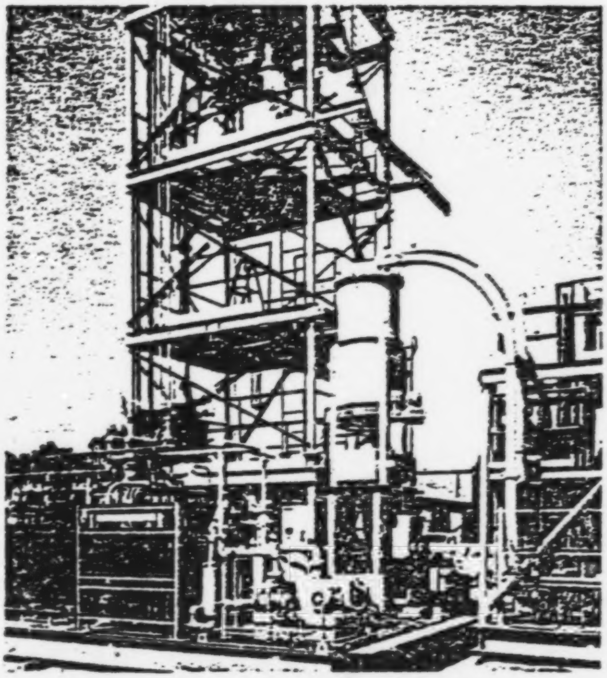
© 1976 Vibra Screw Incorporated

High Reliability and Consistent Accuracy Proven In These Typical Applications

- Master/slave complete dry mixing systems. Flow rates of two or more materials are controlled by slaving other feeders to the master output signal.
- Wet-dry systems. Input rates are controlled by slaving metering pumps to the master output signal (i.e. slurries, adding flavoring to pet food, controlling mixtures in a pelletizing system).
- Critical batching operations. Batch weight, set into a predetermining totalizer, can be controlled to 0.1 to 0.2% ; batching rate can be controlled to ¼% to ½% accuracy, minute-to-minute.
- Wild flow ratio control. When one or more materials must be added by weight to an uncontrolled ("wild") but weighed flow of bulk material, output signals from the bulk "Master" unit control flow of the slaved additive feeders.
- Computerized blending systems. Vibra-Metric Feeders may be interfaced with a computer for continuous monitoring and control of feed rates.

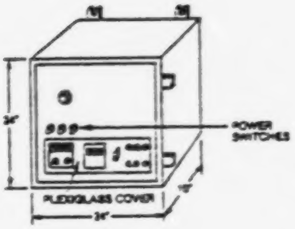


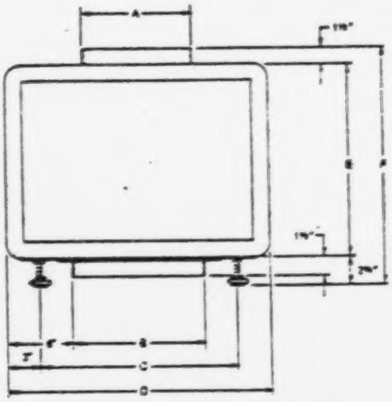
Three Vibra Screw Live Bottom Bin/Vibra-Metric Weigh Belt Feeder combinations assure accurate feed of dry mix ingredients to peanut butter blending operation, eliminating quality control problems. Special Vibra-Metric for peanuts is slaved for operation with either of two Vibra-Metric dry mix feed systems.

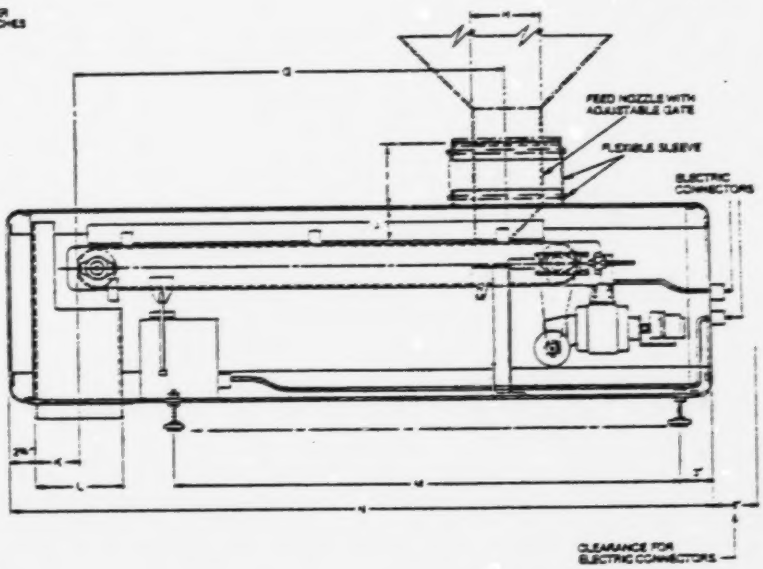


Vibra-Metric/Live Bottom Bin combination is one of the keys to the success of a new "portable" phosphoric acid pilot plant that makes possible simplified evaluation of phosphate rock deposits at a fraction the cost of full-size plant evaluation.

General Features and Options







H
G
FEED NOZZLE WITH ADJUSTABLE GATE
FLEXIBLE SLEEVE
ELECTRIC CONNECTORS
J
2¾"
K
L
M
N
3"
CLEARANCE FOR ELECTRIC CONNECTORS

Standard Features

Feeder Section

- I. ENCLOSURE
  - a. Carbon steel painted machinery green
  - b. Inlet nozzle 304.S.S. with manually adjusted gate
  - c. Discharge nozzle 304.S.S.
  - d. Levelers provided
- II. LOAD CELL
  - a. L.V.D.T. (Linear Voltage Differential Transformer); totally enclosed (dust & water tight)
  - b. Built in demodulator for ac to dc conversion
  - c. Built in dash/pot
  - d. Built in tare system
  - e. Overload to 500 lb.
  - f. Operating temp. 40° to 115°F with no effect
- III. BELT
  - a. Endless teflon coated polyester
  - b. Temperature to 200°F.
- IV. BELT SUPPORT
  - a. Aluminum construction
  - b. Sealed ball bearings
  - c. Rubber coated pulleys
- V. DRIVE MOTOR
  - a. 1/15 to 1/8 h.p. dc
  - b. TENV
  - c. integral T.E. tachometer 0 to 10 volts dc
  - d. 0 to 130 volt operation
  - e. Chain drive to belt
- VI. FLEXURES
  - a. Two-inconel "X"

Controller

- I. ENCLOSURE
  - a. Dust tight hinged front door
  - b. Supplied with 5' long interconnecting cable
- II. CONTROLS & FEATURES
  - a. Digital set point potentiometer
  - b. 3-way selector switch with digital set point readout, rate readout, and belt loading readout
  - c. Percentage feed capacity meter
  - d. Calibrate—run switch
  - e. Switches and pilot lights for control power, weigh belt motor, and auxiliary jack for Bin Gyrator starter
  - f. Fuses for all functions
- III. REMOTE OPERATION
  - a. Standard control may be located 100' max. from feeder
  - b. Booster box available for distances to 1,000 feet

Optional Features

Feeder Section

- I. ENCLOSURE
  - a. Special painting
  - b. Stainless steel construction
  - c. Polishing of inlet and outlet nozzles
  - d. Unit supplied open construction

Controller

- I. ENCLOSURE
  - a. Supplied open for standard rack mtg. (19" x 4" Rack)
  - b. Cable lengths to suit
- II. CONTROLS & FEATURES
  - a. Totalizer 6 digit readout in pounds with manual reset
  - b. Deviation alarm with
    1. High & low set point rate
    2. Red alarm light—Green run light
    3. Output connection ¼ amp. at 12 volts d.c. to actuate customer alarm
  - c. Low level only deviation alarm
    1. Low level set point potentiometer
    2. Red alarm light—Green run light
    3. Output connection ¼ amp. at 12 volts d.c. to actuate customer alarm
  - d. Output signal to customer supplied options
  - e. Recorders
  - f. Capability of accepting input or emitting output signals
  - g. Batching totalizer

General

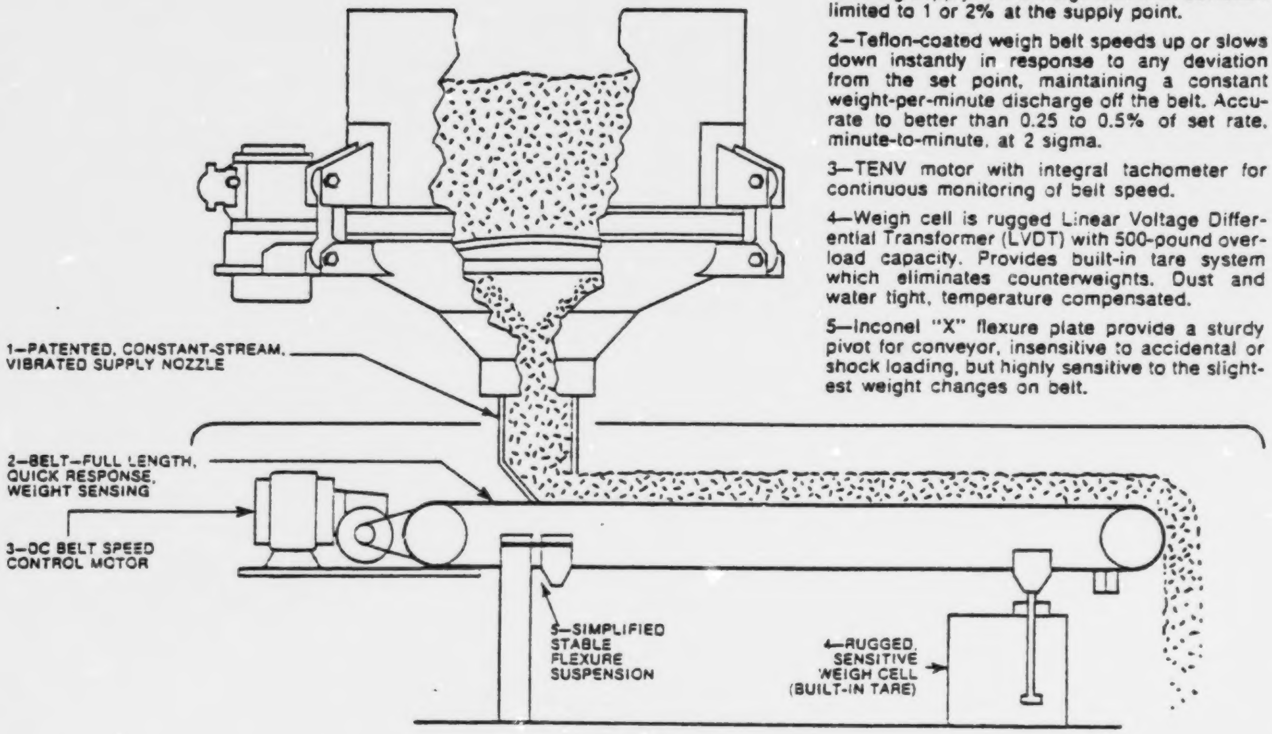
- I. POWER REQUIREMENT
  - a. 115 volts 1 phase 60 Hertz (voltage ± 5 volts)

BELT WIDTH	A	B	C	D	E	F	G*	H	I	J	K	L	M	N
12	10	12	18	24	17¾	21¾	38¼	6	5½	3⅝	4	8	48	64
20	20	20	26	32	19⅝	23¾	39⅝	12	6⅞	5¼	5	10	50	70
24	26	24	30	36	19⅝	23¾	39⅞	18	6⅞	5⅛	5	10	50	70

All dimensions in inches.

*Will vary with "H" dimension.

NOTE: Standard models 2-25 to 8-100 are normally equipped with 12" wide belts; models 16-200 to 32-350 with 20" wide belts; and model 64-700 with 24" wide belts. This may vary depending on material bulk density.


1—PATENTED, CONSTANT-STREAM, VIBRATED SUPPLY NOZZLE
2—BELT—FULL LENGTH, QUICK RESPONSE, WEIGHT SENSING
3—DC BELT SPEED CONTROL MOTOR
5—SIMPLIFIED STABLE FLEXURE SUSPENSION
4—RUGGED, SENSITIVE WEIGH CELL (BUILT-IN TARE)

1—Patented vibrated supply nozzle attaches to vibrated bin bottom. This assures positive, unfaltering supply to the weigh belt with deviation limited to 1 or 2% at the supply point.

2—Teflon-coated weigh belt speeds up or slows down instantly in response to any deviation from the set point, maintaining a constant weight-per-minute discharge off the belt. Accurate to better than 0.25 to 0.5% of set rate, minute-to-minute, at 2 sigma.

3—TENV motor with integral tachometer for continuous monitoring of belt speed.

4—Weigh cell is rugged Linear Voltage Differential Transformer (LVDT) with 500-pound overload capacity. Provides built-in tare system which eliminates counterweights. Dust and water tight, temperature compensated.

5—Inconel "X" flexure plate provide a sturdy pivot for conveyor, insensitive to accidental or shock loading, but highly sensitive to the slightest weight changes on belt.

Principles of Operation

The vibrating bin (A) lays a continuous ribbon of material on the belt (B). This ribbon has a cross sectional area of X by W, where X and W represent the height and width, respectively, of the gate opening.

The belt (B) is driven by variable speed drive (C), resulting in a volume of material per minute X by W by V, where V is the linear velocity of the belt. This results in delivery of pounds per minute at (D).

A load cell, depending upon a fixed excitation voltage (F), senses the weight on the belt (B) and transmits this weight signal to multiplier (G).

Tachometer (H) senses the velocity of the belt and transmits this information to multiplier (G).

Multiplier (G) multiplies the weight of material as sensed by the load cell (E) by the velocity of the belt as sensed by the tachometer (H) and delivers an output at (I) which is proportional to the pounds-per-minute of material.

Set-point potentiometer (J) is set to give corresponding reference signals at (K) which are proportional to dial indications. This indicates the desired delivery rate.

Equalizer circuit (L) compares the desired set-point rate (K) and actual delivered rate (I) and produces correction commands to motor drive (M) which adjusts motor speed (C) to effect adjustments in delivered rate.

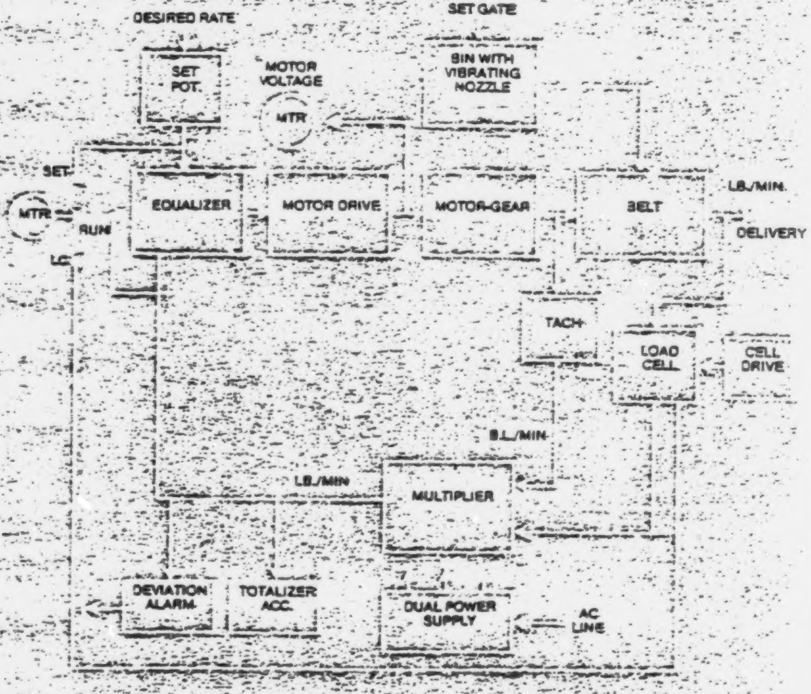
Equalizer circuit (L) contains electrical circuitry to compare (K) to (I) as to its steady-state deviations, rate of change of deviations, and shapes the dynamic reactions of the output to motor drive (M) to produce smooth, non-oscillatory corrections.

Power supply (N) converts normal line AC power to regulated DC voltage for the electronic circuits.

Oscillator (F) generates a very stable high frequency AC voltage to excite the differential transformer in the load cell.

Deviation alarm accessory (O) observes the delivered material rate from multiplier (G) and produces a warning in the event the delivered rate deviates from preset limits.

Totalizer accessory (P) indicates the accumulated weight of material already delivered, and reads out this quantity at the panel.


DESIRED RATE
SET GATE
SET POT.
MOTOR VOLTAGE
MTR
BIN WITH VIBRATING NOZZLE
SET
MTR
RUN
LC
EQUALIZER
MOTOR DRIVE
MOTOR-GEAR
BELT
LB./MIN.
DELIVERY
TACH
LOAD CELL
CELL DRIVE
B.L./MIN
LB./MIN
MULTIPLIER
DEVIATION ALARM
TOTALIZER ACC.
DUAL POWER SUPPLY
AC LINE

Block Diagram

APPENDIX 10

SUPPLIER LITERATURE ON PERIDUR

Enka Industrial Colloids
Postbus 60, 6800 AB Arnhem Holland
Tel. (085) 66 44 22
Telex 45204 enka nl, direct selection: enkak

AKZO

peridur

ORGANIC BINDERS FOR AGGLOMERATION

peridur

APPLICATION: IRON ORE PELLETIZATION

In pelletization and similar operations, organic binders have the inherent advantage that they are eliminated during thermal treatment. This implies that their use does not lead to product contamination, which is unavoidable when conventional binders, such as bentonite, are used.
This brochure describes in detail the development and the use of PERIDUR® as an organic binder in iron ore pelletization.

As far as the properties of PERIDUR are concerned, it not only equals the performance obtainable with high grades of sodium bentonite, such as Wyoming bentonite, but it also offers the following additional advantages:

- a higher resistance to impact breaking (drop test) is achieved without increased pellet deformation;
- the resistance to deformation by overwetting of the pellet surface caused by condensation of steam is improved;
- pellets made with PERIDUR have shown good resistance to thermal shock.

However, the most significant advantage of PERIDUR is that it is harmlessly eliminated during the firing stage, implying that:

- no additional quantities of limestone and coke are necessary, as would be required when using bentonite. This results also in a higher iron content of the pellet.
- especially in the case of direct reduction the decrease in acid-oxide content of the pellets results in a considerable saving in electrical energy required for the melting of the reduced sponge iron. Calculations have shown that a saving in melting costs of up to US$ 2.50 per ton of iron can be expected for each percent reduction in silica content of the pellet.

The results of test work carried out by the Studiengesellschaft für Eisenerzaufbereitung in Othfresen, Germany, have proved that PERIDUR has a unique function in improving the properties of iron ore agglomerates. Reduced pellets, prepared with PERIDUR as a binder, have a high compression strength and, in addition, an extremely high degree of metallization.

®registered trademark
patents have been applied for world-wide

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Telex 45204 enka nl, direct selection: enkak

introduction

In agglomeration operations binders are used to ensure that the properties of the agglomerate are adequate for subsequent processing. So far, only bentonite has performed satisfactorily, although it causes serious contamination of the product.

In iron ore pelletization the addition of 1% bentonite decreases the iron content of the pellet by about 7 kg of iron per ton.
Moreover, bentonite contains a total of 85% of combined silica and alumina. Therefore, the use of bentonite requires additional quantities of limestone and coke. Consequently, for every 1% of bentonite added to the pellet concentrate, the loss of iron per ton of pellet charged to the blast furnace, is increased by 2 - 3% [1].

This product contamination is especially disadvantageous in direct reduction processes. As no melting or refining occurs in the solid state direct reduction process, all the impurities and gangue constituents remain in the metallized product. An additional disadvantage is that acid gangue constituents – alumina and silica – have a significant effect on the power consumption of the electric arc furnace, necessary for the melting of reduced sponge iron.
The penalties associated with acid gangue constituents, are reflected in the productivity and consumption of electricity of the melting furnace used for reduced sponge iron.

The net effect of each percent acid gangue in the pellet concentrate is an increase in power consumption of 15-25 kWh per ton of iron [2-4].
Astier [5] has calculated the influence of acid gangue on the melting costs; every percent additional acid gangue decreases the value of pre-reduced material by US$ 2.00 - 2.50 per ton of product (March 1977), which is in line with other calculations [2, 3].

The disadvantages associated with the use of bentonite, have been known for quite some time and a number of attempts have been made to develop a suitable organic binder to replace bentonite. Notwithstanding the time and the work involved, none of these attempts has been entirely successful so far.
However, the advantages of organic binders over inorganic binders appear to be obvious. For that reason Akzo Plastics decided to reassess the problem. In view of its complexity a development program was set up on a multidisciplinary basis from the very start. Close co-operation was established between experts of the following institutes:

- mineral technology, Department of Mineral Technology, Delft University, Delft, Holland;
- industrial application, Studiengesellschaft für Eisenerzaufbereitung, Othfresen, W-Germany;
- mining chemicals, Akzo Plastics in co-operation with experts in polymer chemistry, ARLA, Akzo Research Laboratories, Arnhem, Holland.

The binder to be developed had to satisfy two main boundary conditions:

- it had to be non-toxic, biologically degradable and, most important, during firing the oxidation products should not be harmful to the environment;
- large-scale production of the binder must be economically and technically feasible.

This has led to the choice of cellulose based polymers.
In view of the world-wide availability on a large scale of the principal raw material, cellulose, a moderate price-profile for the future – when compared to synthetic polymers – can be expected [7]. Consequently, a series of low cost organic polymers was developed. These polymers are commercially available from Akzo Plastics under the tradename PERIDUR®.

Although most work to date has been centred on the agglomeration of iron ore concentrates, some grades of PERIDUR were successfully tested on:

- chromite
- fluorite
- silica sand (foundry)
- nickel-oxides
- sulphide-ore concentrates

Finally it should be mentioned that PERIDUR was also successfully tested in spray-drying operations and in briquetting.

Product information

PERIDUR is a white, freeflowing powder, easily soluble in water.

The binders of the PERIDUR group are based upon various chemical modifications of a natural poly-electrolyte, of which the principal constituents are long chain molecules containing a large number of hydroxyl and carboxyl groups.
These groups, depending on the particular application, can be varied as regards number and spacing. Another important feature is that their aqueous solution can be varied widely in viscosity.

The advantages of these types of binders are that they are non-toxic and biologically degradable. Moreover, the products of high temperature oxidation consist of carbon dioxide and water vapour. They do not contain combustion products harmful to the environment, such as oxides of nitrogen, nor elements which could affect the quality of the steel produced, such as phosphorus and sulphur.

Application

In general PERIDUR is added at about 10 - 20% of the consumption of a high grade sodium bentonite (e.g. Wyoming). The dosage rate ranges from 0.05 - 0.2% and averages about 0.1% (1 kg/ton ore).

Important advantages of such a low dosage rate are of course low storage and transport costs.

Mixing of binders is of extreme importance [26]. This applies to bentonite as well as to PERIDUR, but – in view of the small percentages of PERIDUR involved – the mixing of PERIDUR through the ore concentrate is of critical importance. If the binder is not dispersed evenly enough, optimal results are difficult to obtain.

PERIDUR can be added as a dry powder or as an aqueous solution. Good results also have been obtained by spraying a PERIDUR solution during balling.

For further information and mixing instructions please contact:

Akzo Plastics bv, Industrial Colloids Department
P.O. Box 60 – 6800 AB Arnhem, Holland
Tel. (085) 664422 – Telex 75182 apla nl.

peridur

Peridur as a binder in iron ore pelletization

In the pelletizing process two operations can be distinguished:

1st / The formation of green pellets by rolling moist fine ore in drums, discs or cones at ambient temperature. The green pellets must have adequate strength to survive all types of handling to the firing stage.

The production of good quality green pellets is essential in order to produce high quality fired pellets. Usually this can only be achieved by adding binders to the concentrate.

2nd / The firing of these pellets at temperatures of 1250-1350° C.

As shown in Fig. 1, important features for the production of high quality green pellets are:

- ballability, the balling characteristics (kinetics) of the ore-water-additive mixture
- wet compression strength of the pellet
- resistance to fracture by impact (drop test)
- deformation under load
- resistance to overwetting of the pellet surface by recondensation of moisture onto the green balls in colder layers during drying
- resistance to decrepitation (shock temperature), i.e. sudden pellet-spalling occurring when pellets are heated too rapidly
- dry compression strength

These features have been used for the design and the evaluation of PERIDUR.

The results given on page 6-14 are obtained by using pellets prepared in a laboratory pelletizing disc of 100 cm diameter. Care was taken that the pelletization procedure was the same for all tests.
The concentrate was an enriched magnetite ore with a Blaine number of 1910 cm²/g and a weight percentage of 72.1% minus 0.04 mm.
An 8 kg sample of the concentrate was mulled to break up lumps and to admix the additives prior to agglomeration. During mixing, part of the water required for pelletization was added to the mixture, and the balance of the water was sprayed on the pelletizing disc.
The ore was then hand-fed to the disc over a 5 minute period to produce nuclei. These nuclei were removed and sieved. Fifty grams of the plus 3 mm and minus 4 mm fraction was used to produce the final pellets by continuously adding ore to the nuclei over a 20 minute period.
The pellets were then removed; after sieving, 2000 grams of the plus 12 mm and minus 13 mm fraction were rolled in the disc during 5 minutes. Only this fraction was used for testing.
Addition of water during pelletization was regulated to the point where the produced pellets were showing a slightly water-wet surface.
Throughout the test program a high quality pure sodium bentonite of Wyoming origin was used as a standard for the properties of the pellets.

All the test results are given in good faith but without warranty.

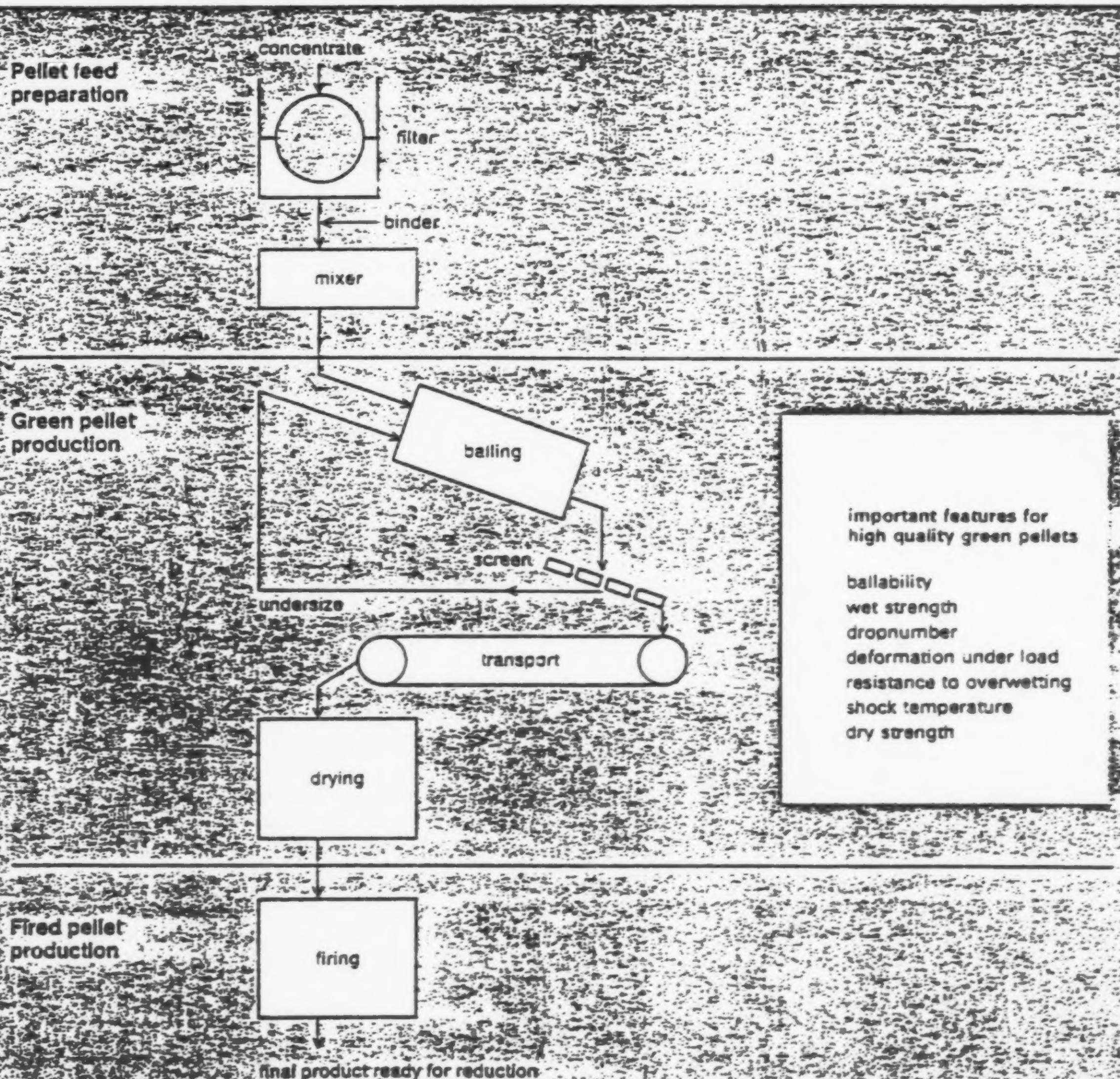

Pellet feed preparation
concentrate
filter
binder
mixer
Green pellet production
balling
screen
undersize
transport
drying
Fired pellet production
firing
final product ready for reduction
important features for high quality green pellets
ballability
wet strength
dropnumber
deformation under load
resistance to overwetting
shock temperature
dry strength

Fig. 1. Typical flowsheet of a pelletizing plant

Ballability

Green ball agglomerates are normally produced by rolling moist fine ore in drums, discs or cones.
Through the rolling action in the drum the ore particles are rearranged and come into contact with each other. At the point of contact the liquid layers around the particles coalesce, causing a reduction of the external surface of the water film. A decrease in the free surface energy of the agglomerate is the driving force for the formation of the nuclei [8]. During the subsequent growth these aggregates are compacted. The porosity decreases and the pore-water is forced to the surface. In this so-called „transition region" the rate of growth is maximal.

Investigations into the mechanism of pellet formation [8-11] have demonstrated that the kinetics of green pellet formation are extremely dependent on the free moisture content of the system.
Each system, dependent on ore and additives, has critical moisture limits within which strong green pellets are formed. At low moisture contents the rate of pellet growth is slow and the pellets are brittle. The rate of pellet growth increases as the amount of moisture increases. Beyond this moisture limit the rate of growth becomes excessive, and the pellets produced are irregular, weak and too plastic. Therefore, there exists a narrow range in which optimum pelletization results are achieved.

Since it is virtually impossible to extract water from the system, it is imperative that the binding additive must have moisture binding ability in order to control the effect of moisture in the feed.
Bentonite, the most common additive, makes less water available to participate in the pelletizing process, due to an intra-crystalline absorption [11].
An organic binder must contain a large number of water-avid polar groups, which are able to realize a temporary immobilization of water.

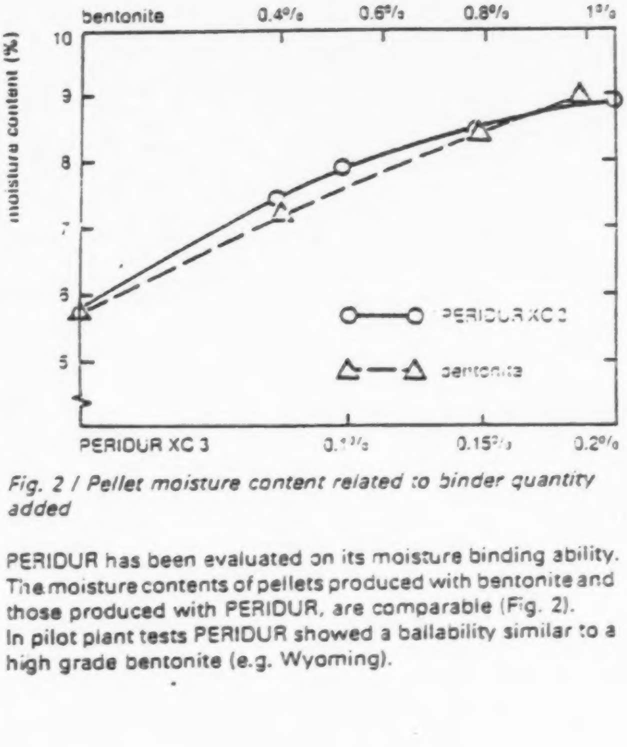


Fig. 2 / Pellet moisture content related to binder quantity added

PERIDUR has been evaluated on its moisture binding ability. The moisture contents of pellets produced with bentonite and those produced with PERIDUR, are comparable (Fig. 2).
In pilot plant tests PERIDUR showed a ballability similar to a high grade bentonite (e.g. Wyoming).

The freshly formed wet pellets must have adequate strength to withstand conveying and screening during transport to the drying and firing section.

The models and formulae developed for the theoretical strength of moisture-filled agglomerates [14-16], have provided useful guidelines for the development of PERIDUR. For example: Rumpf's formula for the tensile strength of moist agglomeratie gives:

$$\sigma_t = constant \cdot \left[\frac{1-\epsilon}{\epsilon}\right] \cdot \frac{\gamma}{d} \cdot \cos\theta$$

where

σ_t = *tensile strength*
ϵ = *agglomerate porosity*
γ = *surface tension*
d = *mean particle size*
θ = *contact angle at the liquid,*
air, solid-interface

Although the existing theoretical models are obviously inadequate to explain quantitatively the mechanism of pellet failure under compression, it is clear that high wet strength is favoured by low porosity and small mean particle size.

The binder to be used should have the following properties in order to obtain high wet strength:

- it should not decrease the surface tension of the agglomerate moisture;
- it should increase cos θ, i.e. improve wetting of the particles by the liquid in the agglomerate pores.

The addition of PERIDUR does not affect the water-air interfacial tension.
The Kossen-method, developed at the Technical University of Delft [17], was used to measure the effect of PERIDUR on the angle of contact at the solution-air-solid contact area. PERIDUR decreases this angle of contact [18].
Although the results of the contact angle measurements can only be applied qualitatively, the Kossen-method proved to be a useful tool to select and evaluate the parameters of the binder molecule which are responsible for the good wet strength of the agglomerate.

The wet strength of a pellet is determined by compressing pellets individually until failure occurs, either at a constant rate of loading or at a constant rate of deformation.
With the constant deformation rate tester, the measured load at fracture is higher than with a constant loading rate tester.

Unfortunately, test methods have not yet been standardized throughout the industry. Therefore, to compare compression test results as obtained in different laboratories, the test conditions have to be given [19].

Further, the pellets must be neither too brittle nor too plastic when submitted to the drying process.
Brittle pellets will break into many fine particles, decreasing pellet-bed permeability, whereas too plastic pellets will not break at all but will flatten under load. This hampers the pellet-bed permeability seriously.

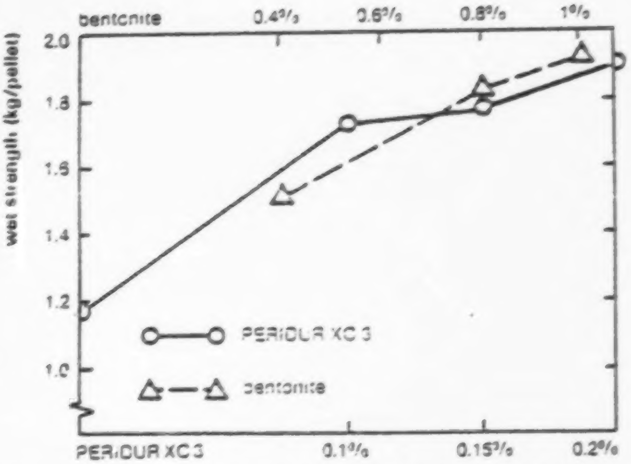


Fig. 3 / Wet strength related to binder quantity added

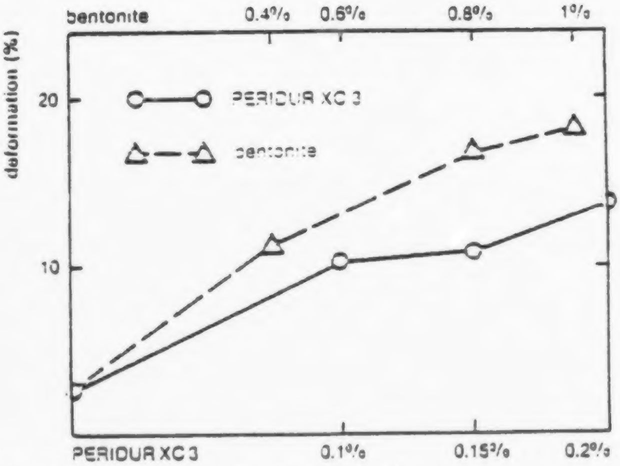


Fig. 4 / Pellet deformation at 1 kg load

Therefore, wet strength of the pellets must be considered in connection with pellet plasticity [13].

The wet strengths presented in Fig. 3, are determined by compressing the pellets to failure at a constant rate of 0.3 mm/s.

A linear displacement transducer is connected to the moving piston of the compression test equipment in order to plot a load versus deformation curve on a recorder.

The percentage of the pellet deformation at a 1 kg load is presented in Fig. 4.

Pellets produced with PERIDUR instead of bentonite are shown to have remarkably less deformation at comparable wet strength levels.

Resistance to impact failure (drop test)

The capillary model of Rumpf has been extended by Wada and Tsuchiya [20], who developed a „visco-capillary bonding model".

This model considers the contribution to pellet strength resulting from capillary pressure as well as from the viscosity of the interstitial liquid.

One important conclusion drawn from the visco-capillary model, is that the resistance to fracture by impact (drop test) is viscosity-dependent. This is because the rate of deformation is about 1000 times the rate for the slow compression testing.

The drop test is an important qualitative test for estimating the ability of green pellets to withstand the drops encountered during transport to the induration section.

The test procedure normally used, is to drop freshly formed pellets repeatedly from a height of 45 cm until cracks appear at the pellet surface. The dropnumber is the average number of drops the pellet can withstand.

Comparative drop test results with PERIDUR and bentonite are shown in the Figures 5 and 6.

Good quality green pellets have dropnumbers in the region of 5 - 15. Dry and brittle pellets have lower values, whereas pellets with very high values are generally considered to be too plastic for processing.

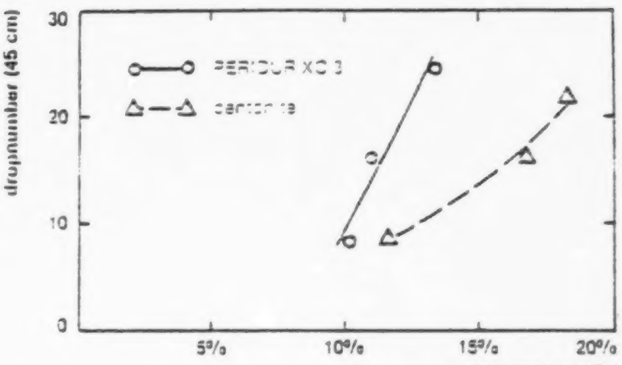
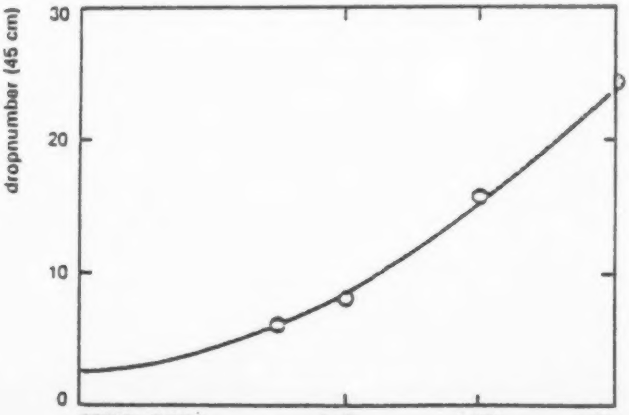
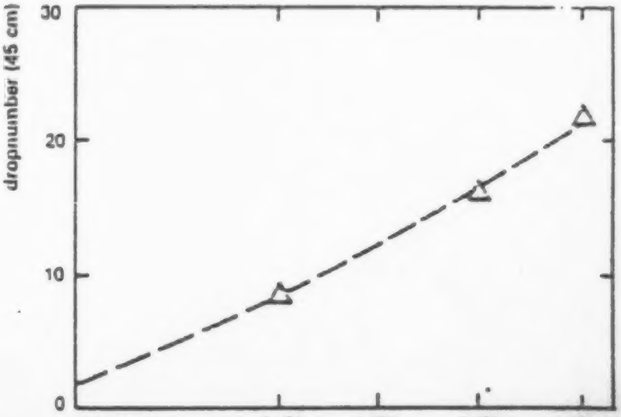


Fig. 7 / Dropnumber versus percentage pellet deformation at 1 kg load

However, when the linear deformation determinations of pellets with PERIDUR and Wyoming bentonite as an additive are related to their corresponding dropnumbers, it becomes obvious that for PERIDUR higher dropnumbers can be allowed compared with a conventional binder, such as bentonite (Fig. 7).

In practice this means that higher dropnumbers – often required for pellet transport – can be tolerated without endangering pellet-bed permeability.





Resistance to overwetting by condensation of steam

Condensation of steam on the surface of pellets in the colder layers can cause pellet deformation by overwetting.
This usually results in clustering of the pellet-bed.

In the condensation test, simulating these conditions, green pellets are individually exposed to steam of 100° C under a 185 g load (Fig. 8).
The time required for total disintegration of the individual pellet, is determined.

As shown in Fig. 9, PERIDUR as a binder provides a better resistance to overwetting, compared with a high grade of bentonite.

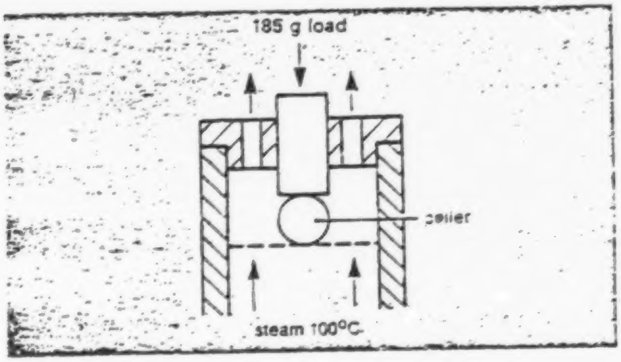


Fig. 8 / Condensation test

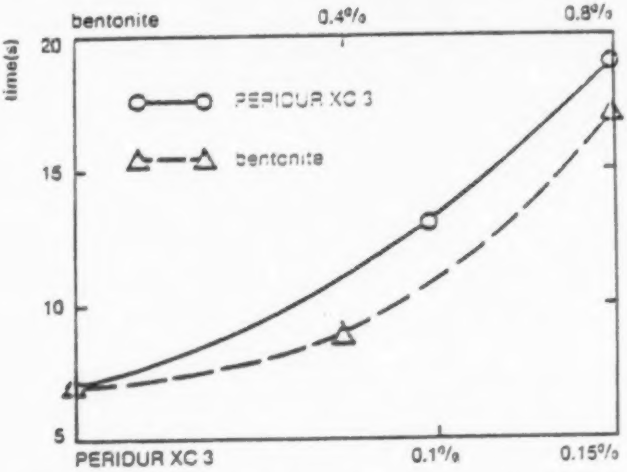


Fig. 9 / Time until green pellets totally disintegrate through condensation of steam

During the drying process in a shaft furnace or on a travelling grate, the wet green pellets are rapidly heated.
When the moisture inside the pellets vaporizes more quickly than it escapes through the available pores, a steam pressure is developed in the centre of the pellet.
Spalling of pellets will occur when the internal pressure of the generated steam exceeds the tensile strength of the pellet.
Resistance of the pellet to this type of thermal spalling is called „shock temperature".

The shock temperature is defined as the temperature at which a maximum of 10% of the tested wet pellets crack when they are suddenly heated for 5 minutes at this temperature. The test procedure is standardized by LKAB in Sweden [21].

The mechanism of thermal spalling can be described by means of the Kozeny-Karman equation [18]:

$$\Delta p = K \cdot \frac{\eta}{d^2} \cdot \frac{[1-\epsilon]^2}{\epsilon^3} \cdot L\upsilon$$

where

Δp = *the pressure drop resulting from flow through a porous system of equal-sized spheres*

K = *the Kozeny-Karman constant*

η = *the viscosity of the solution*

d = *the particle diameter*

ϵ = *the porosity*

L = *the depth of the agglomerate*

υ = *the velocity of flow (drying rate)*

From the Kozeny-Karman equation it can be derived that the spalling tendency augments with increasing agglomerate size as well as with drying rates and decreasing particle size and porosity. This is in accordance with the experimentally observed facts.

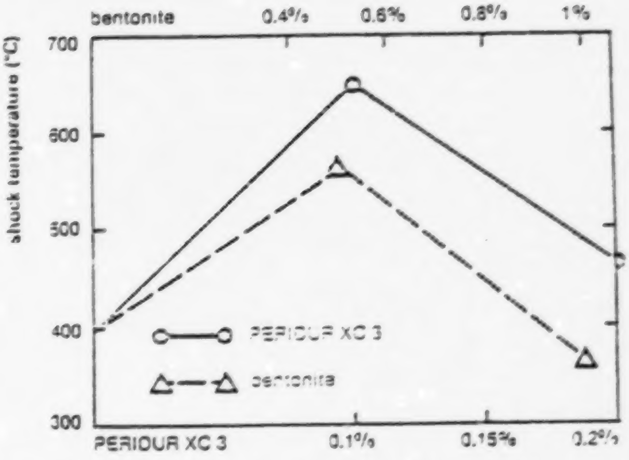


Fig. 10 / Shock temperature of pellets related to binder quantity added

The addition of binders has the counter-acting effect of increasing both the viscosity of the liquid and the porosity of the pellets.
Kozeny-Karman suggests that there could be an optimum rate of addition with regard to spalling resistance.
This has also been confirmed experimentally.
The results of the shocktemperature tests, conducted according to the LKAB procedure, are presented in Fig. 10.

The improvement of the condensation resistance as well as of the shock temperature suggests that PERIDUR allows higher drying rates.

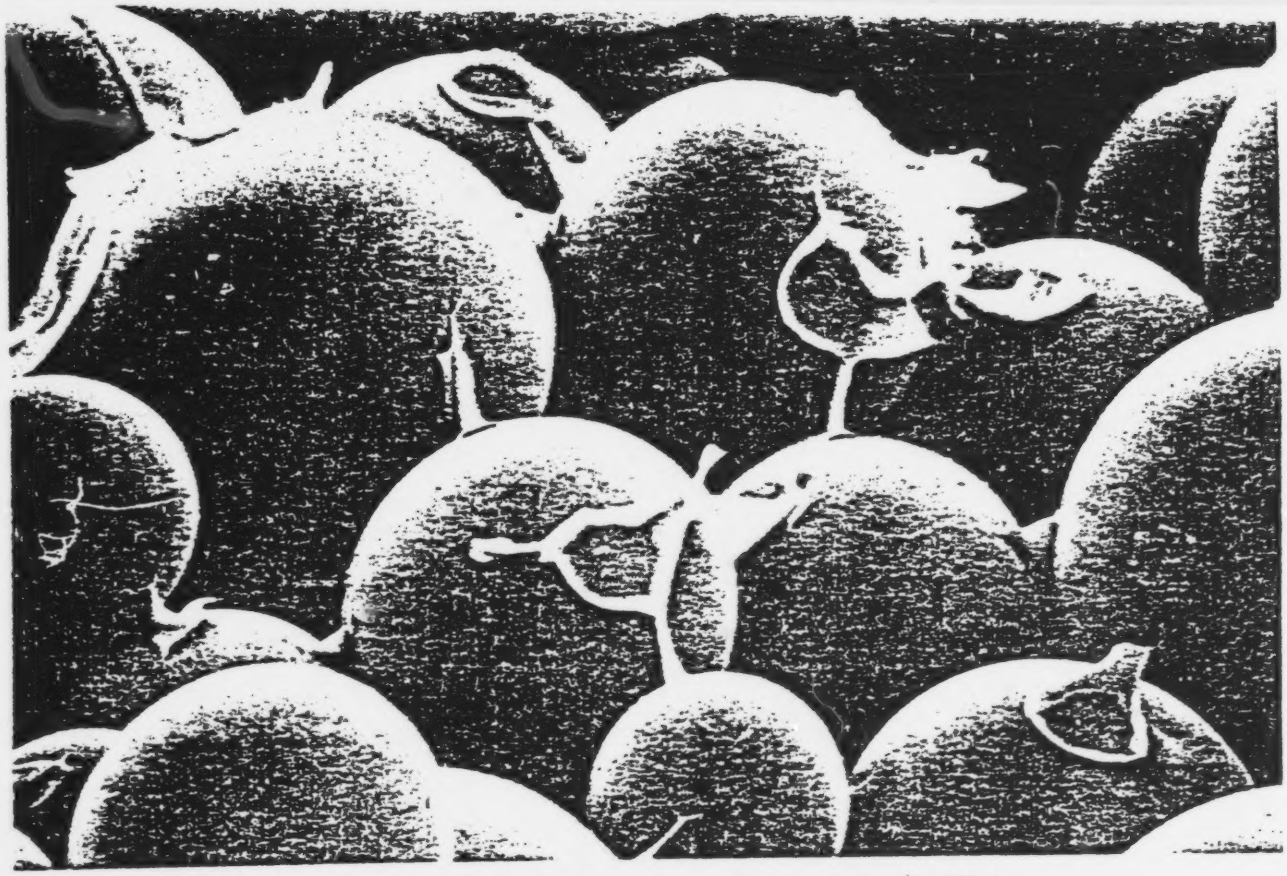
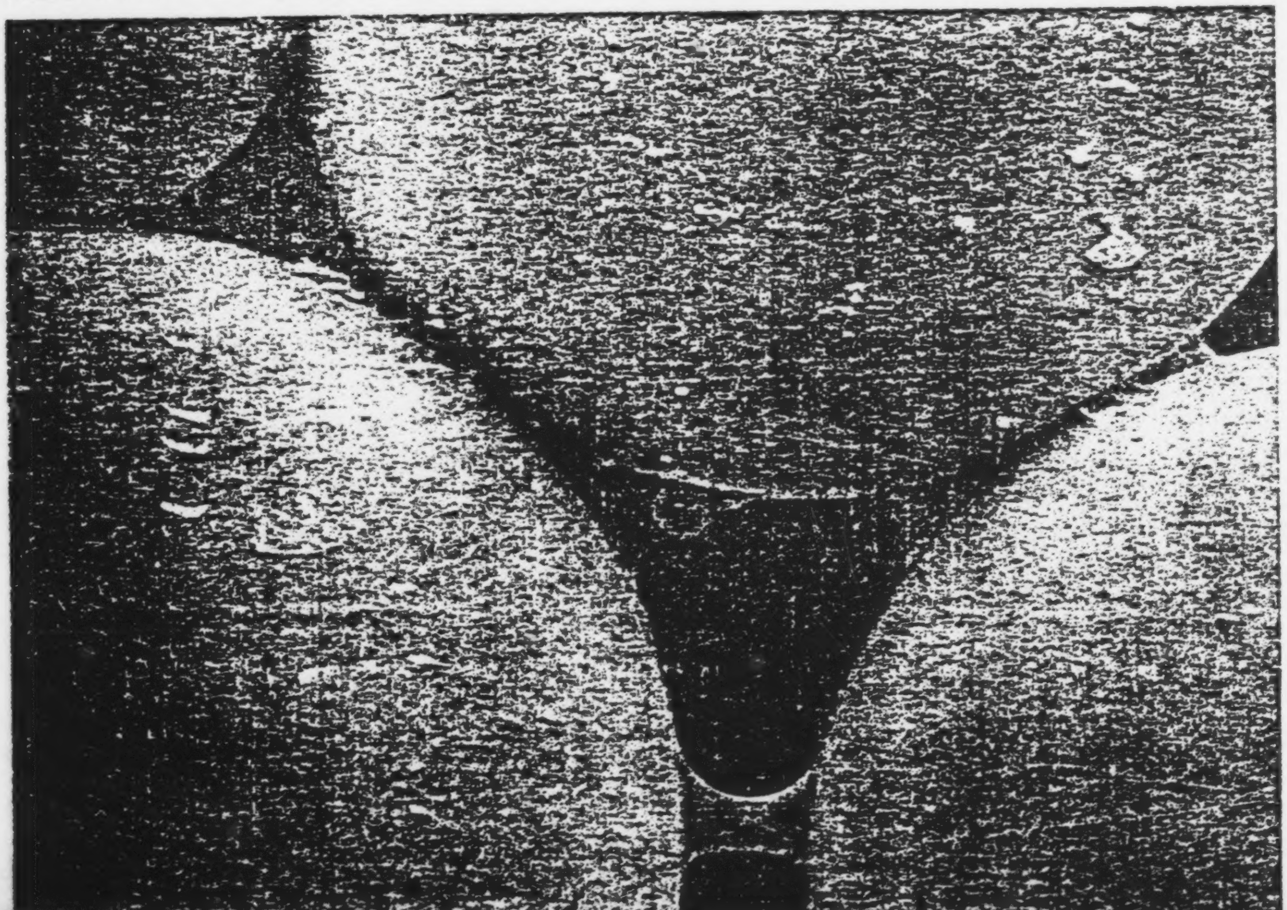


Photo 1/Scanning electron photograph of the rupture plane of a broken glass spheres pellet (magn. 600 x)

Photo 2/Pellet surface showing bridges of PERIDUR at the points of contact (magn. 2500 x)



Although organic binders are eliminated during high temperature induration, they may have an indirect influence upon the mechanical (e.g. compressive strength, abrasion resistance) and metallurgical properties (such as reducibility) because of their influence on structure and texture (including porosity and pore size distribution).

In order to investigate the fired pellet properties and to confirm the test results obtained with PERIDUR XC3 in the laboratory, pilot plant tests were carried out on different magnetite and haematite concentrates by Studiengesellschaft für Eisenerzaufbereitung Othfresen (Liebenburg, W. Germany).

The chemical composition, the data on specific surface and sieve analysis of the pelletized concentrates are given in the Table below.

concentrate	Fe	FeO	SiO_2 + Al_2O_3	CaO + MgO	Blaine	<0.04 mm
	%	%	%	%	cm²/g	weigth %
Magnetite I	71.3	31.4	1.17	0.02	2010	94.8
Magnetite II	71.4	30.2	0.65	0.20	1920	72.1
haematite	68.7	–	0.97	0.04	2200	-

Magnetite concentrate I was obtained by wet weak-field magnetic separation after proper grinding and subsequently enriched by reverse flotation.
Concentrate II was prepared by means of a wet weak-field magnetic separation only. Both concentrates were obtained from a low-grade ore.

For each test a batch of 80 kg pellets was prepared on a pelletizing disc. The properties of the wet pellets are given in the Tables I and II. The results obtained with PERIDUR XC7 (a grade of PERIDUR with a higher water-binding ability) are given as well.

binder	none	bentonite		PERIDUR XC3		PERIDUR XC7
quantity added (%)		0.5	1.0	0.1	0.2	0.1
water content (%)	8.8	9.2	10.1	9.4	9.3	9.9
dropnumber	2.5	2.7	21.3	8.0	16.4	26.9
green strength (kg/p)	1.0	1.0	1.55	1.61	1.36	1.15
dry strength (kg/p)	0.6	2.34	5.17	2.56	5.59	2.09
shock temperature (°C)	400	575	375	650	475	575

Table I / Pilot plant results
Magnetite I concentrate

concentrate	magnetite II		haematite
binder	bentonite	PERIDUR XC3	PERIDUR XC3
quantity added (%)	0.8	0.15	0.15
water content (%)	9.0	9.6	9.6
dropnumber	40.0	45.1	13.5
green strength (kg/p)	1.76	1.77	2.15
dry strength (kg/p)	7.17	5.68	5.41
shock temperature (°C)	350	500	400

Table II / Pilot plant results
Magnetite II concentrate; haematite

Fired pellet properties

The pellets to be tested were fired in the pot grate.

Cold compressive strength is determined by loading pellets individually to failure. The average value of 60 tested pellets is reported.

The tumble test is carried out in compliance with ISO/TC 3271/1975 standards, using a tumbler, 500 mm wide and 1000 mm in diameter with two lifters of 50 mm height [22]. The tumble charge consists of 15 kg pellets, having a size of 6.3-40 mm.
The tumble index is the plus 6.3 mm fraction and the abrasion index is the minus 0.5 mm fraction, expressed in weight percentages.

The chemical and mechanical properties of the fired pellets are given in table III.

The elimination of PERIDUR during firing is responsible for a higher porosity of the pellets, implying that an improvement in the reduction properties can be expected.

concentrate	magnetite II	magnetite II	haematite
binder	bentonite	PERIDUR XC3	PERIDUR XC3
quantity added (%)	0.8	0.15	0.15
firing temperature (°C)	1320	1320	1280
compressive strength (kg/pellet):			
mean	290	283	445
minimum	150	150	180
maximum	520	515	720
ISO-tumble test			
tumble index (%)	97.4	95.0	93.9
abrasion index (%)	2.2	4.6	4.2
chemical analysis			
Fe (%)	68.5	69.2	68.8
FeO (%)	1.2	0.8	0.75
SiO_2 (%)	1.14	0.50	n.d.
porosity of the pellets (vol. %)			
at 800° C	32.9	38.6	n.d.
at 1320°C	22.5	25.8	n.d.

Table III / Properties of fired pellets

Properties of the fired pellets in direct reduction

Direct reduction is receiving increased world-wide attention as an important step in steelmaking and the future growth potential for direct reduction is remarkable.
Annual capacity in the Western hemisphere will be some 32 million tons in 1980 [23].

For direct reduction processes, pellets of the highest quality are necessary in order to provide a suitable feed for electric furnace steelmaking.
Only the use of organic binders ensures the lowest possible contamination.

In view of these important facts, the pilot plant work was focussed on direct reduction.
In the test work the metallurgical as well as the mechanical properties of pellets produced with PERIDUR XC3 were investigated.
The quantity of PERIDUR added was 0.15% (1.5 kg per ton ore), while limestone was used for basicity control.

Tests for determining the direct reduction behaviour are carried out at a lower temperature (750° – 1000° C) than normally used in conventional testing.
In particular, reduction rate, disintegration and sticking behaviour are of interest [22].
Pellet disintegration is investigated by a modified Linder test, whereas sticking and reducibility are determined in a vertical furnace during reduction under load.

The direct reduction tests have shown that with PERIDUR XC3 as a binder, pellets of high quality (metallurgical as well as mechanical) were produced at an extremely high rate of reduction.
These direct reduced pellets had high compressive strengths and an extremely high degree of metallization.

In order to investigate pellet disintegration during reduction, a modified type of Linder test [24] was carried out in a furnace, 540 mm long and 150 mm wide, rotating at 3 rpm. The drum contains four 20 mm high lifters.
The pellets were heated up in 12-14 min. from 300° C to 600° C in a reducing atmosphere (22% CO, 30% H_2, 21% CO_2 and 27% N_2). Reduction then continued isothermally for three hours at 800° C.
The gas composition and the flow were kept constant during the test: 32% CO, 50% H_2, 2% CO_2 and 16% N_2 at 1.08 Nm^3 per hour.
Subsequently the pellets were cooled in nitrogen and sieved by hand through 6.3 mm and 0.5 mm screens.
The weight percentage of the minus 0.5 mm fraction (abrasion index) is a measure for disintegration during reduction.

The results are presented in table IV together with the cold compressive strength and the degree of metallization of the plus 6.3 mm fraction.

The pellets with PERIDUR XC3 as a binder showed to have a high resistance to disintegration as well as a very high compressive strength after reduction. Furthermore, the reduced pellets have an extremely high degree of metallization (98.3%).

weight percentage of	+ 6.3 mm fraction	98.8
	+ 3.15 mm fraction	99.3
	− 0.5 mm fraction	0.3
compressive strength (kg/p)		238
chemical analysis		
Fe total (%)		95.77
Fe metal (%)		94.16
degree of metallization (%)		98.31

Table IV / Disintegration of pellets magnetite II; 0.15% PERIDUR XC3, 2% limestone

Reducibility and sticking

Sticking behaviour of pellets was investigated in a vertical furnace, according to the test method developed by Burghardt and Grebe [25].

In the test a bed of pellets was reduced isothermally during three hours under a static load of 1 kg/cm². Gas composition was 50% H_2, 32% CO, 16% N_2 and 2% CO_2 and the gasflow 1.2 Nm³ per hour.

The degree of reduction related to the time of reduction was determined by continuously measuring the loss in weight of the material. Important features are:

- reducibility, which is the loss in oxygen per minute at 40% degree of reduction, expressed as a percentage;
- the time (in minutes) required to achieve 80% degree of reduction;
- the degree of reduction after 180 minutes.

Pellet-bed permeability, measured by continuously recording the drop in gas pressure through the bed, is an indication for the reduction strength, i.e. the resistance of the pellets to disintegration and deformation (softening) under load in a reducing atmosphere.

After the reduction the pellets were cooled in nitrogen and screened.

The weight percentage of the plus 16 mm fraction is a measure for the sticking and should be less than 5%. Furthermore, the cold compressive strength and the chemical composition of the pellets were determined.

Results of the tests are presented in table V.

- The pellets proved to have a high reducibility and a high degree of metallization (up to 99.3%).
- A gas drop could not be measured, implying that no deformation (softening) or disintegration occurred.
- The compressive strength of the pellets was very high.

concentrate	magnetite II		haematite
limestone (%)	1	4	1.8
reducibility	1.14	1.38	0.94
degree of reduction after 180 minutes (%)	96	99	96
80% degree of reduction obtained after (minutes):	70	79	87
gas pressure drop (mmW)	0.0	0.0	0.0
weight % + 16 mm fraction	3.6	0.0	0.0
compressive strength of reduced pellet (kg/p)	72	162	176
chemical analysis			
Fe total (%)	96.5	96.34	95.76
Fe metal (%)	95.87	94.61	94.42
degree of metallization (%)	99.35	98.20	98.6

Table V / Reducibility and sticking (reduction temperature 800°C); PERIDUR XC3 quantity added 0.15%

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APPENDIX 11

RECOMMENDED POT GRATE TEST PROGRAM (PHASE II)

PERIDUR AS BENTONITE SUBSTITUTE

RECOMMENDED POT GRATE TEST PROGRAM
(Phase II)

Binder Type :	Greek Bentonite	Peridur	Peridur	Peridur	Peridur	Peridur	TOTAL
Addition Level (kg/t)	8.0	0.50	1.00	1.50	2.00	OPTIMUM	
No of Test Series:	1	2*	2*	1	1	3	10
Type of Pot Grate Tests:	Quality	Quality	Quality	Quality	Quality	T. Profile	
No. of Pot Grate Tests:	2 (dupl.)	4 (dupl.)	4 (dupl.)	2 (dupl.)	2 (dupl.)	3-6	17-20
No. of Test Days:	1	2	2	1	1	2-3	9-10

Testing of Pellet Properties

Green Balls :
- Moisture
- Drop
- Wet Compression
- Dry Compression

Fired Pellets:
- Compression
- Tumble (ISO) and Abrasion Index
- LTD (2% H2)
- Swelling
- Porosity
- Reducibility
- Save samples for High Temperature Softening Tests elsewhere

*Notes: Two (2) green ball moisture ranges, 8.3-8.5 and 8.7-8.9 %

A. Mai
03/21/85

APPENDIX II

REPORT ON RESULTS OF TEST PHASE II A

IRON ORE COMPANY OF CANADA

OFFICES — BUREAUX
SEPT-ILES, QUEBEC
MONTREAL, QUEBEC
SCHEFFERVILLE, QUEBEC
LABRADOR CITY, NEWFOUNDLAND — TERRE-NEUVE
ST. JOHN'S, NEWFOUNDLAND — TERRE-NEUVE

Proposal DSS No. 03SQ.23440-4-9316

DEVELOPMENT OF A TECHNICALLY AND ECONOMICALLY ACCEPTABLE SUBSTITUTE BINDER FOR BENTONITE FOR USE WITH CAROL LAKE CONCENTRATE

REPORT ON RESULTS OF TEST PHASE IIA

Submitted to

DEPARTMENT OF SUPPLY AND SERVICES CANADA

August 15, 1985

A. Mai

A. Mai
Project Engineer

G. Chung

G. Chung
Project Manager

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1.0 SUMMARY

Following the first phase of development work on bentonite substitutes for iron ore pelletizing, a series of pot grate tests were carried out to determine whether Peridur could be used as a binder to produce pellets of acceptable quality.

The testwork was performed at the Hanna Research Center in Nashwauk, Minnesota using Carol Lake iron ore concentrate.

Data obtained from the comparative study confirmed that at dosages of equivalent binder cost, green pellets produced with Peridur were inferior in quality to bentonite-based green pellets. Marginal green strength, drop index and dry strength could be obtained only at a significantly higher addition of the organic binder.

The poor properties of Peridur green balls resulted in sub-standard physical quality of fired pellets. This appeared to be caused partially by the insufficient absorption of filter cake moisture. Attempts to improve the physical characteristics of pellets with additional heat input and/or longer indurating time showed only limited success.

On the other hand, the metallurgical properties of fired pellets, especially reducibility, were far better with Peridur.

The current specifications for iron ore pellets are established primarily on physical properties, which generally could not be sacrificed in favor of the metallurgical characteristics. Therefore, the use of Peridur would be limited to special cases.

For this reason, it is recommended that the previously proposed machine test on Peridur (Phase IIB) be abandoned. The study should proceed with Phase III to determine the suitability of other potential bentonite substitutes.

2.0 INTRODUCTION

A study on potential substitutes for bentonite as an iron ore pellet binder was co-sponsored by the Department of Supply and Services Canada and the Iron Ore Company of Canada. Refer to Proposal DSS No. 03SQ.23440-4-9316 (Reference No. 1).

Phase I of the study involved the application of Peridur, a commercially available cellulose-based polymer binder. Emphasis of that phase was to determine the effects of Peridur on green ball formation. Experiments were conducted on one production balling module at the Carol Pellet Plant. The findings were summarized in Reference No. 2.

The second phase of the study was to evaluate the effects of Peridur on the induration process of iron ore pellets. This phase was divided into two parts, first in a laboratory (Phase IIA), then on a production induration machine (Phase IIB), if encouraging data were obtained.

Phase III of the study would evaluate other potential binders in a laboratory test program.

The following report summarizes the results of Phase IIA.

3.0 OBJECTIVES OF TEST PHASE IIA

The primary objective of Phase IIA was to determine the effects of Peridur as a binder on the physical and metallurgical quality of fired pellets. Furthermore, the pot grate tests were performed under varying indurating conditions in order to determine which process modifications, if any, would be required to obtain optimum product quality and machine productivity.

To meet the objectives, a test schedule was established (Refer to Table I). It was expected that this schedule would be modified during the course of the program based on the results of the initial tests.

4.0 SELECTION OF TEST FACILITIES

The Hanna Research Center of Nashwauk, Minnesota, was selected among the qualified laboratories to conduct the testwork required for Phase IIA.

The selection was based on technical competence, experience with testwork of similar nature, as well as cost considerations.

During the test program, progress of the work was monitored by representatives of the Iron Ore Company of Canada and the Scientific Authority Officer assigned by CANMET. Both were also present at the test site to witness the experiments and discuss the findings with the contracted laboratory.

5.0 DESCRIPTION OF TEST MATERIALS AND TEST PROCEDURES

5.1 Test Materials

For the required testwork the following samples were shipped to the Hanna Research Center by the Carol Pellet Plant.

Iron Ore Concentrate

The typical pellet plant filter discharge sample contained approximately 1% coke breeze. The following analysis was determined (dry basis):

	%
Fe	66.2
SiO_2	4.5
Magnetite	33.1
Moisture	8.8
+ 0.147 mm	2.1
- 0.044 mm	68.8
Surface Area (Blaine)	1630

Bentonite

A representative sample of bentonite used by the Carol Pellet Plant was sent for base line tests. The product originated from Milos, Greece. A typical analysis is as follows:

	%
SiO_2	62.3
Al_2O_3	16.44
Na_2O	2.66
K_2O	1.83
LOI	5.61
Plate Index	636
Enslin Index	595

Peridur

Peridur was supplied by ENKA Industrial Colloids of Arnhem, Holland. Details of the product specifications are included in Reference No. 2.

5.2 Balling Test Procedures

a) Balling Feed Mix Preparation

The balling feed was prepared in 91 kg charges and mixed in a Simpson Mix-Muller. Half of the concentrate charge was layered into the mixer followed by a layer of the binder. The second half of the concentrate charge was then placed on top. The Muller was started and any moisture addition was accomplished during the first minute of mixing. The Muller then mixed moist feed for an additional 5-6 minutes. The mix was discharged into the balling disc table feeder.

- This process was repeated until sufficient mix had been prepared for a full day of testing. Mix was made fresh each day.

b) Balling Tests

Balls were produced in a 1.2 m pan type disc (Refer to Appendix 1). Angle of disc, feed location and water sprays were adjusted according to balling characteristics of the mix. On-size balls were discharged onto a conveyor and were collected in 7.5 L pails (approximately 12 kg). Pails were covered with water saturated towels to prevent drying of balls throughout the day.

5.3 Pot Grate Test Procedures

Appendix 1 shows the pot grate test equipment.

Pots were initially tared (with all thermocouples and hearth layer), then green balls were added until the desired bed depth was reached. While the pot was being charged, thermocouples were placed at three desired bed locations (Hearth Layer/green ball interface, center of bed and 2.54 cm below top of bed). Hearth layer was separated from green balls by a screen to prevent mixing when discharging the pot.

Weight was noted for proper bed depth. For all succeeding tests this weight was used. Two rope rings were placed around the perimeter of the bed to minimize air leakage between refractory and green balls.

The Pot was then loaded into furnace and fired according to a machine cycle. Controlling parameter was the pressure drop across the bed and set point was maintained by adjusting oil and gas flow. Air flow was recorded at 1 minute intervals by a technician, and controlled by rotary vane meters.

During the firing, bed temperatures, inlet and outlet gas temperature, casting temperature and bed pressure drop were recorded on a strip chart recorder. Oxygen gas content was also monitored in the inlet gas and oxygen was injected to maintain a minimum of 14% oxygen in the gas stream.

After firing and cooling the charge, the pot was removed and weighed. The bed was then raked out and visually inspected for spalling, cracking deformation, slagging, etc. Depending on the requirement, the bed was sampled as top, middle and bottom sections or as a single sample for performing quality tests.

The test flowsheet is shown in Figure 1.

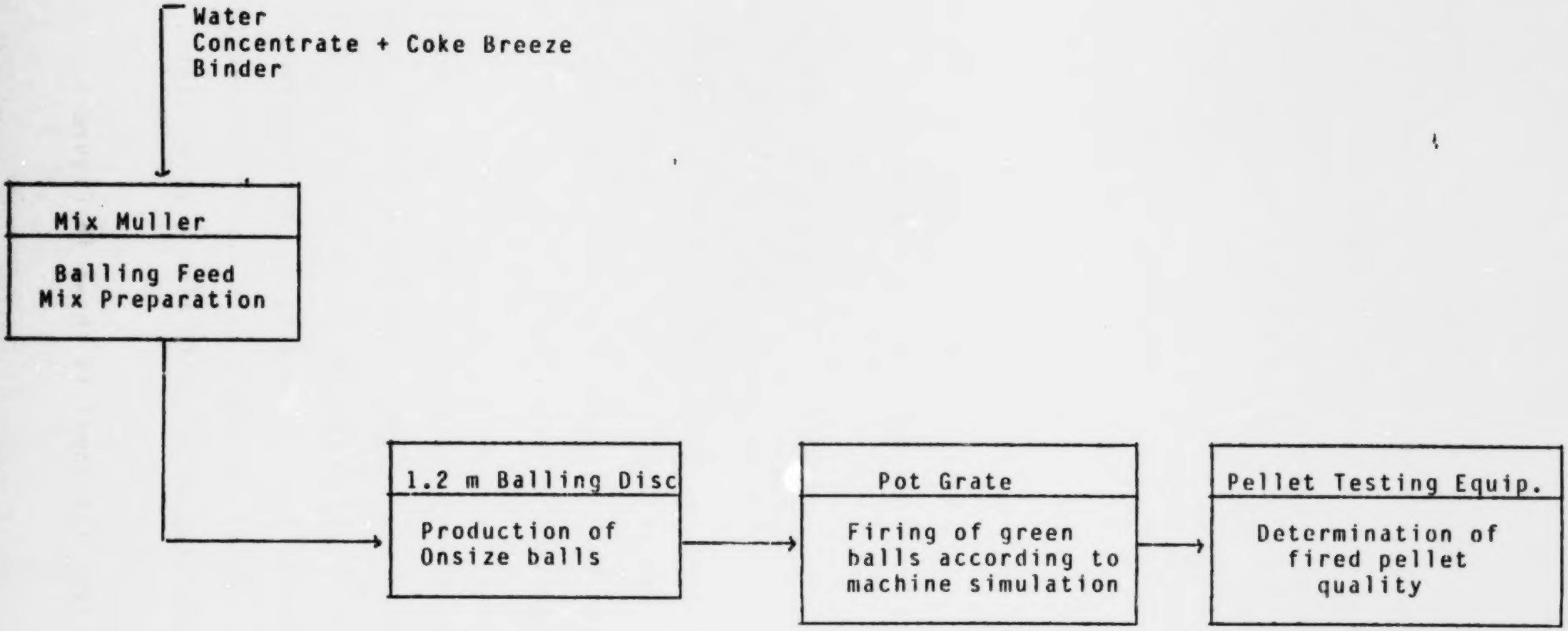
Water
Concentrate + Coke Breeze
Binder
Mix Muller
Balling Feed
Mix Preparation
1.2 m Balling Disc
Production of
Onsize balls
Pot Grate
Firing of green
balls according to
machine simulation
Pellet Testing Equip.
Determination of
fired pellet
quality

Figure 1 - Test Flowsheet

5.4 Pellet Quality Evaluation

The following characteristics of green balls were determined:

- moisture content
- drop index
- wet compression
- dry compression

Details of the procedures for these determinations are shown in Appendix 2.

The fired pellets were evaluated on:

A) Physical Properties

Fired Compression
Tumble Index
Porosity (Mercury Immersion)
Size Structure

B) Metallurgical Properties

ISO Reducibility
ISO Low Temperature Disintegration
ISO Free Swelling

Details of the procedures for testing quality of fired pellets are shown in Appendices 3 and 4.

6.0 TEST RESULTS

The results of the test series are summarized in Table II.

6.1 Balling Test Results

The data indicated the following points:

a) Green balls quality improved with increasing addition of Peridur.

b) For a filter cake with a moisture of 9.0%, marginal green balls were produced at an addition of 0.10% Peridur (dry weight basis). Green balls of equivalent quality as the current bentonite green balls could only be produced at an addition rate of 0.15% Peridur. It should be noted that the bentonite cost equivalent addition level for Peridur is approximately 0.05% (dry weight basis).

c) No significant change in quality of Peridur green balls was obtained as the filter cake moisture was reduced from 9.0 to 8.5%.

In general the results of the batch balling tests confirmed the finding of Phase I that the green ball properties were poorer when bentonite was substituted with Peridur.

6.2 Pot Grate Test Results

Since the main objective of Phase IIA was to study fired pellet quality, indurating conditions were the principal process parameters of the test series. In addition to zone temperatures, the pressure drop and bed depth were also varied to determine the optimum firing cycle for the Peridur-based green balls.

A total of 18 firing tests were performed. The test conditions and results are shown in Table II. The report by the Hanna Research Center is attached as Appendix 5.

The following points were established:

a) Severe "packing" of Peridur pellets was observed at the top of the bed when the standard firing cycle was used. This phenomena is probably due to Peridur's inability to immobilize the condensed water at low dosage levels (0.05 - 0.1%). Consequently, a localized dissolution of pellets occurred, resulting in a mud that plugged the bed. This, in turn, significantly affected the gas flow, causing poor compression strength and abrasion resistance of pellets, especially those at the bottom of the bed.

The "bed packing" was more severe at a high filter cake moisture (9%) and a low Peridur addition level (0.1% or lower, dry basis).

b) Attempts to improve the physical quality of pellets by increasing pressure drop in firing zones, lowering bed depth and increasing firing temperature produced only limited success. In all cases, the pellet properties of tumble and compression strength were inferior to those obtained with bentonite.

c) When the balling moisture was decreased to 8.5%, marginal to acceptable physical qualities of pellets could be obtained. However, in most pellet plants, such a low filter cake moisture could only be achieved at considerable expense.

d) The metallurgical properties of the Peridur based pellets indicated an increase in reducibility, as well as an improvement in low temperature disintegration and swelling characteristics.

7.0 DISCUSSION AND CONCLUSIONS

Pot grate test data confirmed that at the normal balling moisture of approximately 9.0%, the application of Peridur as a binder resulted in unacceptable physical pellet properties. It was also established that these marginal qualities of Peridur green balls could not be significantly improved by a higher energy input in the form of additional fuel consumption and/or fan power.

The use of Peridur as a binder for materials similar to the Carol iron concentrate may be limited to two cases:

a) when the filter cake moisture is reduced to less than 8.5% and/or

b) when the current specifications on physical properties of pellets are relaxed in exchange for the improved metallurgical qualities.

It should be emphasized that the results were obtained from only testwork on Carol concentrate. The values and trends are not necessarily universal to all ore types or process conditions of individual pellet plants.

8.0 RECOMMENDATIONS

Pot grate tests normally produce better results than an actual pellet plant under similar process conditions. Therefore, it is reasonable to assume that the originally proposed Phase IIB (machine test) would produce negative results. Considering the high cost for such a test, it is recommended that this phase be abandoned.

It is also recommended that Phase III be initiated to investigate the feasibility of other binder alternatives.

LIST OF REFERENCES

No. 1 Proposal DSS No. 03SQ.23440-4-9316 Development of a Technically and Economically Acceptable Substitute Binder for Bentonite for Use with Carol Lake Concentrate. Submitted by Iron Ore Company of Canada, dated February, 1985.

No. 2 Report on Results of Test Phase I. Submitted by A. Mai and G. Chung, Iron Ore Company of Canada, dated March 29, 1985.

LIST OF APPENDICES

1 Test Equipment

2 Procedures for Determination of Green Ball Properties

3 Procedures for Determination of Physical Properties of Fired Pellets

4 Procedures for Determination of Metallurgical Properties of Fired Pellets

5 Report on Pot Grate Test Results by Hanna Research Center

APPENDIX 1

Test Equipment

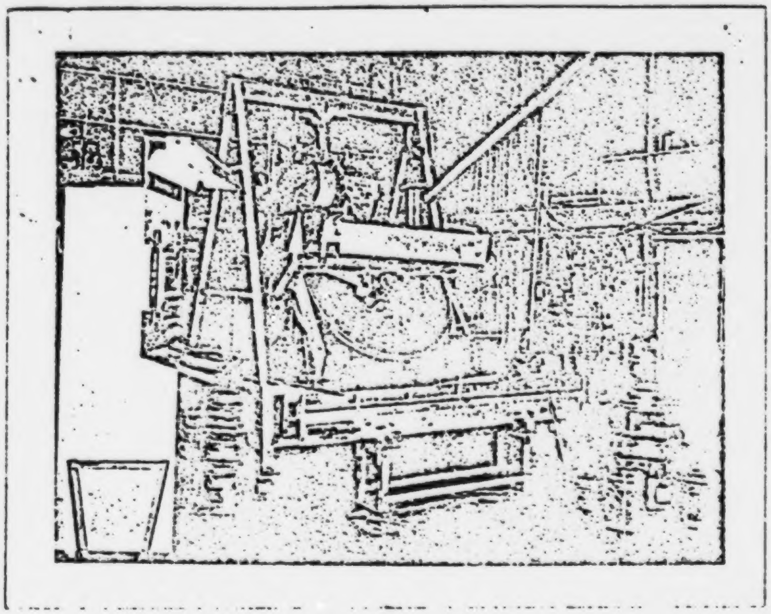

FIGURE 1: 1.2m Balling Disc

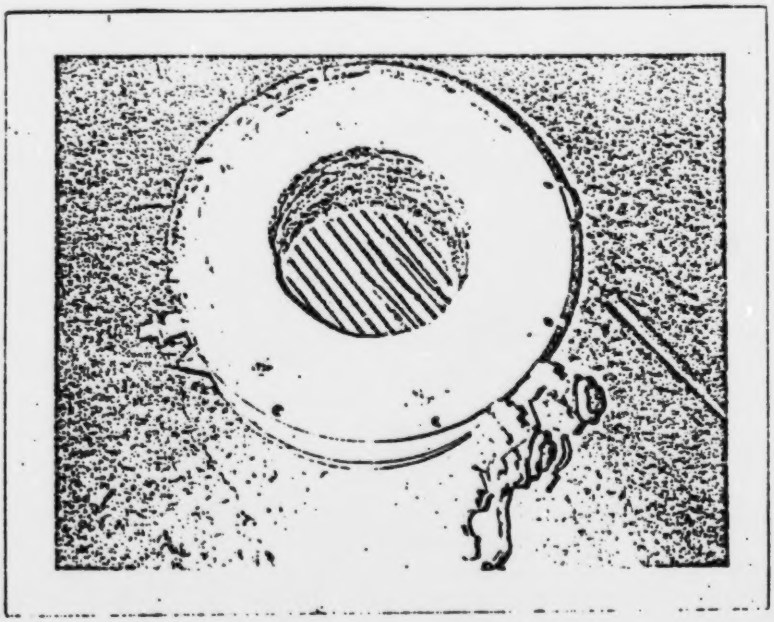

FIGURE 2: Pot Section

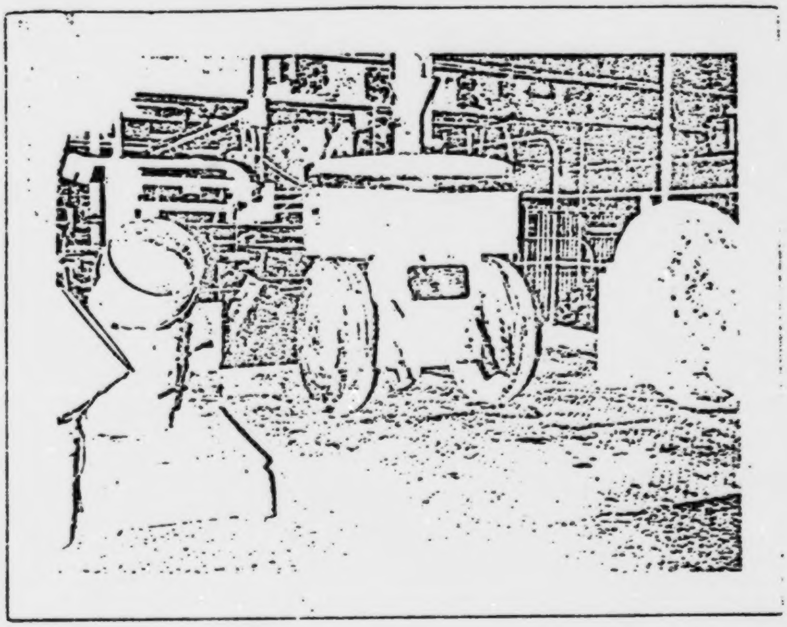

FIGURE 3: Mix Muller

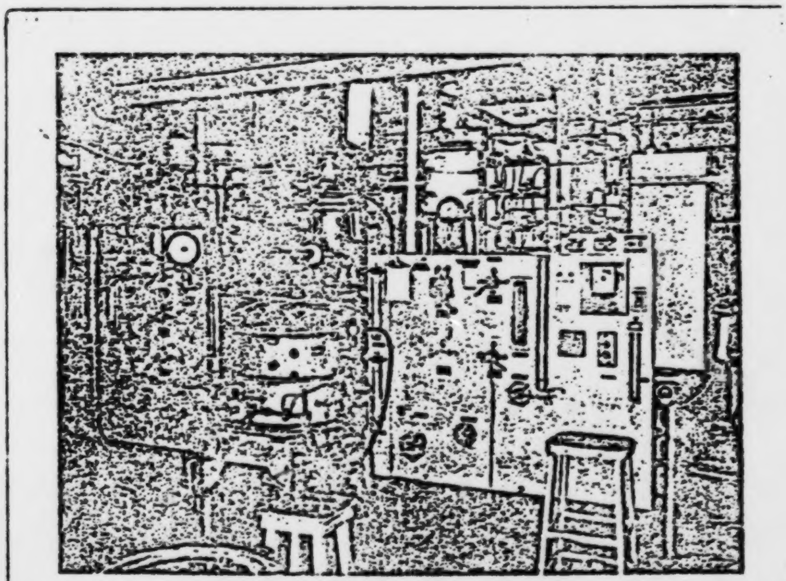

FIGURE 4: Pot Grate System

APPENDIX 2

Procedures for Determination of Green Ball Properties

PROCEDURES FOR DETERMINATION OF GREENBALL PROPERTIES

To minimize the effects of green ball size variations on physical quality, only ½" ∓ 1/64" diameter pellets are submitted for quality testing. Besides determining the moisture content of the balls (gravimetric; wet basis), the following tests are conducted:

1. Wet Drop Strength - Moist balls are dropped from an 18" height onto a steel plate until the first sign of failure occurs. The number of drops required to produce failure is recorded.

2. Wet Compressive Strength - Moist balls are compressed to failure at a constant loading rate of 34.25 lb/min. The gross pounds required to produce failure are reported.

3. Dry Compressive Strength - Wet balls are dried overnight at 250°F. and then compressed to failure at a constant loading rate of 34.25 lb/min. The gross pounds required to produce failure are reported.

4. Moisture Content - The moisture content is the weight loss (in percentage) of green balls after being dried at 105°C. for 24 hours.

Designation: E 946 − 83

Standard Test Method for
WATER ABSORPTION OF BENTONITE POROUS PLATE METHOD[1]

This standard is issued under the fixed designation E 946; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the determination of water absorbency of bentonite.

1.2 Bentonite is a montmorillonite clay material. It is added to moist iron-ore concentrates as a binder in forming balls prior to heat treatment in the agglomerating process for making iron-ore pellets.

2. Applicable Documents

2.1 *ASTM Standards:*

D 1193 Specification for Reagent Water[2]

E 1 Specification for ASTM Thermometers[3]

E 145 Specification for Gravity-Convection and Forced-Ventilation Ovens[4]

E 832 Specification for Laboratory Filter Papers[5]

3. Summary of Method

3.1 The amount of water absorbed over an 18-h period by a 2-g sample of processed bentonite is determined gravimetrically by difference under specific fixed conditions and is calculated from the absorption equation in 11.2.

4. Significance and Use

4.1 The effectiveness of the bentonite is partially due to its water absorption capacity that relates to the quantity of the bentonite required to reach desired wet- and dry-ball strengths. The absorption test relates to the effectiveness.

4.2 The absorption test aids the supplier in determining his mining and processing requirements for meeting specifications. It aids the user in evaluating the effectiveness of the bentonite in the balling process.

4.3 This test method is not to be used to determine the effectiveness of the use of additives to bentonite to enhance the water absorbing properties.

5. Definitions

5.1 ***absorption***—water absorbed by the bentonite expressed as a percentage of the dry weight of the bentonite sample.

5.2 ***bentonite***—montmorillonite-form of absorptive colloidal clay used in processing iron-ore concentrates in preparation for heat hardening.

5.3 *plate*—sintered alumina plate.

6. Technical Precautions

6.1 Several conditions materially affect the test and these conditions are as follows:

6.1.1 Accumulation of soluble salts and fungal growth in the water affects the absorption properties of bentonite,

6.1.2 Absorption is temperature sensitive,

6.1.3 Absorption value is affected by time,

6.1.4 Loading density in grams per square centimetre has an important bearing on the sensitivity of the test, and

6.1.5 Water level has a significant effect on test results. It is, therefore, mandatory that the procedure for the test be adhered to carefully.

7. Apparatus (See Fig. 1)

7.1 *Sintered Medium Coarse Aluminum Oxide Plate*, 12 by 12 by 1-in.[6], having 19 permeability units per plate, an approximate pore size of 154 μm and a particle retention of 68 μm.

7.2 *Inert Support Pad*, ¼-in. thick by 1-in.^{2} (4 required).

7.3 *Shallow Flat Base Glass Pan*, approximately 16 by 16 by 3 in.[7]

7.4 *Glass Cover*, 17 by 17 in. having a soft gasket strip to form a seal against the pan.

7.5 *Hardened Filter Paper*, 9-cm diameter. See Specification E 832.

7.6 *Drying Oven*, controllable to 105°C. See Specification E 145.

7.7 *Balance*, having a ±0.001-g sensitivity.

7.8 *Tared Covered Containers*, 10 cm diameter.[8]

7.9 *Thermometer*, accurate to ±1.0°C. See Specification E 1.

7.10 *Washer Type Template*, with a 5-cm diameter cut out for use in depositing the bentonite on the 9-cm filter paper.

8. Materials

8.1 *Bentonite Samples*, from the supplier or user inventory, ground to approximately 80 % of minus 200 mesh and dried to a constant weight at 105°C (221 °F). The bentonite is described in 1.2.

8.2 *Distilled Water*—See Specification D 1193, Type II.

9. Procedure

9.1 Place a clean alumina plate, that is supported by ⅛-in. thick inert pads, in the center of the pan and ensure the top of the plate is level. Before each test, add distilled water to within ⅛ in. of the top of the plate, measuring to the water-plate contact, at least ⅛ in. away from the edge of the plate, then place the glass cover over the pan.

9.2 Allow the system sufficient time to reach ambient temperature.

9.3 Determine the average weight of a hydrated filter paper from the lot used in the absorbency test, by allowing four papers to absorb water on the alumina plate for 18 h and then weighing the papers.

9.4 Weigh 2 g (±1 mg) of processed bentonite, previously dried to constant weight at 105°C (220°F), onto the dry filter paper and spread it evenly within the 5-cm circle of the template on the 9-cm diameter paper. This can best be accomplished by using a vibrating spatula.[9] Remove the template and brush any remaining particles on top of the sample. Remove the template.

9.5 Place the paper and bentonite on the alumina plate. Up to four samples can be placed on the plate at one time.

9.6 Record the initial water temperature.

9.7 After 18 h, record the final water temperature. Carefully lift the filter paper and place it in a preweighed covered glass dish. Place a cover on the dish until ready to weigh.

9.8 Weigh the covered glass dish containing the hydrated paper and the hydrated bentonite.

9.9 Following each test, the water should be changed and the plate and pan cleaned.

10. Calculation

10.1 Determine the net weight of the hydrated bentonite by subtracting the glass dish weight and the average weight of the hydrated paper from the total weight.

10.2 Calculate and report the absorbed moisture, as to the percent weight increase, over the dry bentonite weight as follows:

$$\text{Absorption, \%} = \frac{(Ww - Wd)}{Wd} \times 100 - (K(Ta - Tr))$$

where:

Absorption = water absorption (% weight) at 20°C/18 h,

Ww = net weight of hydrated bentonite, g,

Wd = net dry weight of dry bentonite, g,

Ta = average of initial and final water temperature, °C,

Tr = reference temperature 20°C, and

K = temperature coefficient (weight, %/°C) = 3.30.

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[1] This test method is under the jurisdiction of ASTM Committee E-16 on Sampling and Analysis of Metal Bearing Ores and Related Materials and is the direct responsibility of Subcommittee E16.04 on Testing (Physical).

Current edition approved May 27, 1983. Published July 1983.

[2] *1983 Annual Book of ASTM Standards*, Vol 11.01.

[3] *1983 Annual Book of ASTM Standards*, Vol 14.01.

[4] *1983 Annual Book of ASTM Standards*, Vol 10.01.

[5] *1983 Annual Book of ASTM Standards*, Vol 14.02.

[6] Norton Industrial Ceramics Division, 50 N.W. Bond St., Worchester, Mass. 01606, Product #P-260 has been found satisfactory for this purpose.

[7] Glass pans are available from Scientific Supply Houses.

[8] Reference Fisher Scientific Catalogue 81, Reusable Petri Dish, Catalog No. 08-747-C, 100 by 15 mm diameter set has been found satisfactory for this purpose.

[9] Vibrating spatula manufactured by Mettler has been found suitable.

11. Precision and Accuracy

11.1 No statement is made about either the precision or the accuracy of Test Method E 946 for measuring water absorption of bentonite, since the result merely states whether there is conformance to the criteria for success specified in the procedure.

TABLE 1 Derivation of Temperature Correction Factor, K[A]

Sample Number		77-219	77-218	77-230	78 292	76-40
18-h Average Water Temperature,		Water Absorption, Weight, %				
°F	(°C)					
63	(17 2)	664	907	756	745	579
73	(22 8)	650	938	768	751	606
		660	919	795	759	610
82	(27 8)	671	932	795	767	620
		676	942	781	787	624
Regression Analysis Slope, weight, %, °C		1 14	4 14	3 13	2 81	1 26

[A] Average temperature correction factor (slope) = 1 30 % weight/°C and 1 83 % weight/°F.

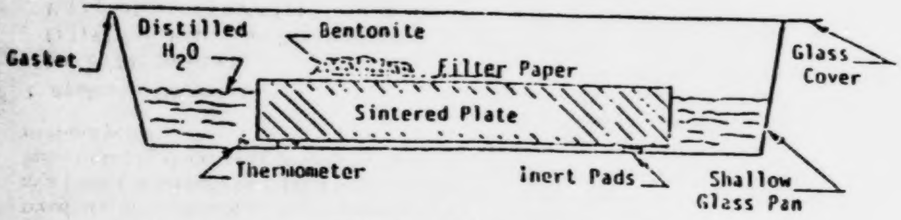

FIG. 1 Example of an Apparatus

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This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, 1916 Race St., Philadelphia, Pa. 19103.

RELATED MATERIAL

Any documents included in this section that are marked "proposed" are published for information only. They have received the approval of the sponsoring technical committee for publication as "proposed," but have not been officially accepted by the Society. Comments are solicited and should be addressed to ASTM, 1916 Race St., Philadelphia, Pa. 19103.

SPECIFIC GRAVITY

CONDENSED OPERATING INSTRUCTIONS
AIR COMPARISON PYCNOMETER

1. Open coupling valve and remove sample cup. Rotate both reference and measuring handwheels counterclockwise to rest against stops. (Be sure both handwheels are against stops before going to step 2.)

2. Turn measuring handwheel clockwise until starting number is set on counter. When doing this do not go past the no. If you should go past or under the number then back off to the stop again and repeat.

3. Place sample in cup. Insert cup in compartment. Lock sample cup in place by pressing handle down firmly.

4. Wait 15 seconds. Then close coupling valve.

5. Turn both handwheels simultaneously clockwise or alternately until reference handwheel rests against stop. Keep pointer on scale during this process.

6. Wait ten seconds. Bring pointer to null with measuring handwheel.

7. Open coupling valve. Read counter. Reads sample volume directly in cc's to the second decimal place.

8. Rotate handwheels counter clockwise to stops to release pressure before removing sample cup.

9. Calculation - Sample wt. in grams ÷ by sample volume in cc's = specific gravity.

Note: For accurate measurements do the following:

1. Clean the sample cup and make several zero measurements with the cup empty. Record these zero values. Average the consistent values.

2. Run both ball standards several times and record these values. Average the consistent values.

3. Calculation:
   a. If zero reading is low (below zero) this means that the air pycnometer is reading low and this amount below zero must be added to the sample volume. If the zero reading is high this amount above zero must be subtracted from the sample volume.

   b. The amount that the standard ball volume is low must be added to the sample reading while the amount that the standard ball volume is high must be subtracted from the sample reading.

   c. When possible try to pick a sample weight which will have a volume near the standard sample volume of 28.96 cc or 8.58 cc. To do this estimate the specific gravity of the sample and multiply it by 28.96 cc or 8.58 = grams of sample. If the volume of the sample is about 20 cc or between the volumes of the standard sample then average the deviation of the large and small ball standard and apply this correction factor.

Examples

Zero reading = 999.96 (.04 too low)
large ball = 29.85 (.11 too low)

Sample reading = 26.51 (average)

Corrected sample reading = 26.51 +.04 +.11 = 26.66 cc.

Zero reading = 000.03 (.03 too high)
large ball = 29.02 (.06 too high)
Small ball = 8.60 (.02 too high)
Average ball deviation = $\frac{.06 + .02}{2} = +.04$

Sample reading = 18.67

Corrected sample reading = 18.67 - .03 - .04 = 18.60 cc.

Sample weight determination

Sample - Taconite concentrate
Estimated S.G. = 5.0
Sample Wt. = 5.0 × 28.96 = 144.8 grams (Use a sample of 140-145 grams)

BLAINE SURFACE AREA PROCEDURE

A. Sample Preparation

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1. Break up the lumps in the dried sample by passing it through a . . mesh screen.

2. Mix the sample and carefully split out about 100 gms.

3. Demagnetize the sample, if it is a magnetic concentrate.

4. Place sample in a shallow pan and saturate with alcohol to disintegrate fine lumps and clusters.

5. Dry the sample in the pan on the steam table or in the steam cabinet. Avoid overdrying or baking of the sample.

6. Hand screen the sample on 100 mesh screen, saving and weighing the plus and minus fractions.

7. Hand screen the minus 100 mesh fraction once again on 150 mesh to break up any small lumps and clusters. Avoid breaking down the sample by excessive rubbing.

8. Recombine the plus and minus 150 mesh products and mix carefully on a small cloth. If magnetic flocculation persists, demagnetize once again.

9. Transfer sample to properly labeled paper envelope.

B. Surface Area Determination on -100 Mesh Fraction

1. Calculate the sample weight to be used in the surface area determination by the following formula.

$W_s = (SG_s)(VB)(1-e)$

Where $W_s = (SG_s)(VB)(1-e)$

W_s = Sample Weight, Gms.

SG_s = Specific Gravity of Sample

VB = Calibrated Volume of Bed in Blaine Unit, cc.

e = Desired Bed Porosity. 0.5 is normally used.

2. Spot a sample out of the envelope and weigh out calculated portion on top loader balance. Weights accurate to ±0.01 gm. are sufficient.

3. Check to see that the screen is properly seated in the Blaine apparatus sample holder.

4. Slip the filter paper disc into the sample holder and seat it on the screen, using a short piece of rubber tubing.

5. Transfer the sample to the Blaine test cell, holding the funnel slightly up from the cell.

6. Place the top filter paper into the cell.

7. Carefully insert the bakelite plunger and depress, rotating slowly, to its full depth. Slowly remove the plunger.

   Caution - Do not bump or jar the test cell at any time after the sample is in place.

   NOTE: If the plunger does not seat without applying excessive pressure, the porosity chosen was wrong and the determination should be repeated at a higher porosity. Likewise, if the sample fits too loosely in the cell, the porosity is too high and another run should be made at a lower porosity.

8. Place the test cell in position on the Blaine unit making sure it is sealed to the unit. Use stop-cock grease to insure seal.

9. Place finger over test cell to seal it off and carefully raise liquid level in the U-Tube to the top line by means of the squeeze bulb and valve.

10. Release finger and time the fall of the meniscus between timing lines on the U-Tube with a stop watch.

11. Repeat Steps 9 and 10 for a total of 3 readings. Average the results. (If the time of fall is over 100 seconds, one or two readings are sufficient.)

12. Record readings on Blaine Surface Area Work Sheet.

13. Remove the sample from the cell by inverting and pressing out with a short piece of rubber tubing. Wipe cell and screen clean with a paper wipe.

14. Submit completed worksheet to a secretary for processing.

Apparent Pellet Specific Gravity or Mercury Immersion

1. Fill a 400 ml beaker with ≈175 cc's Hg.
2. Record the weights of the samples to be tested.
3. Place the beaker on the balance and position the immersion screen in the mercury, adjusting it by loosening the ringstand clamp, while moving the screen up or down until it is just covered by the mercury, mark this position on the ringstand. This mark will serve as the reference setting used in the following steps.
4. Record the weight with the screen immersed to the reference mark and then tare the balance. Now remove the screen from the mercury, being careful so as to remove as little mercury as possible on the screen.

DO NOT TARE THE BALANCE AGAIN!!!

5. Using the screen, immerse the sample lowering the screen to the reference setting, record the weight. If the quantity of sample is too great to be entirely immersed at one time, divide the sample up. Each part of the sample should be immersed and the weights recorded. When the entire sample has been immersed the weights should totaled up.
6. Divide the total weight found in Step 5 by 13.55 (den. Hg = 13.55 g/cc). This will give the volume of the sample.
7. Divide the sample weight by the volume found in Step 6 to determine the sample density.

STRUCTURE

Pellet Screen Structure - Ten pounds, more or less, of fired pellets are screened on the following square mesh screens for 1 minute on the Gilson screen shaker. The weight percent remaining on each screen is calculated from the individual screen weights. The screens most commonly used are 1/2", 3/8", 5/8", 1/4 Mesh and 28 mesh.

MOISTURE

1. Split out a representative sample.

2. Record wet weight and dry at 105°C.

3. $\% \text{ Moisture} = \left[\frac{\text{Wet Wt.} - \text{Dry Wt.}}{\text{Wet Wt.}}\right] \times 100$

BULK DENSITY

1. Fill the standard bulk density container (vol = 0.1 ft^3) with pellets and level off the top.

2. Weigh the container and pellets then substract the tare wt. of the container to get weight of pellets.

3. Bulk density $\frac{\text{lbs}}{\text{ft}^3}$ = (Wt. of pellets)(10)

APPENDIX 3

Procedures for Determination of Physical Properties of Fired Pellets

Designation: E 279 – 69 (Reapproved 1974)

Standard Method of

TUMBLER TEST FOR IRON ORE PELLETS AND SINTER[1]

This Standard is issued under the fixed designation E 279; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval.

1. Scope

1.1 This method provides a relative measure of the resistance of iron ore pellets and sinter to degradation by impact and by abrasion.

2. Summary of Method

2.1 The sample is placed in a tumbler drum which is rotated. The tumbled material is removed and screened to determine the degradation.

3. Apparatus

3.1 *Tumbler Apparatus*, as shown in Fig. 1, shall be a circular drum 914 mm (36 in.) in inside diameter and 457 mm (18 in.) in inside length constructed of steel plate at least 6.3 mm (¼ in.) in thickness. The drum shall be replaced whenever the thickness of the plate is reduced by wear to 3.18 mm (⅛ in.) in any area. Two equally spaced steel angle lifters, 50.8 by 50.8 by 6.35 mm (2 by 2 by ¼ in.) shall be solidly attached longitudinally inside the drum by riveting in such a manner as to prevent accumulation of material between the lifter and drum. Preferably, one of the lifters shall be attached to the door for ease of sample removal. The lifters shall be fastened so that the attached legs point away from the direction of rotation, thus giving a clear unobstructed shelf for lifting the sample. The lifters shall be replaced when the wear is such that the shelf measures less than 47.6 mm (1⅞ in.). The door shall be so constructed as to fit into the drum to form a smooth inner surface and during the test shall be rigidly fastened to prevent any loss of the sample. The drum shall be rotated on stub axles about 38.1 mm (1½ in.) in diameter attached to the ends of the drum by means of flanges welded or bolted so as to provide smooth inner surfaces. The apparatus shall be fitted with a revolution counter and, preferably, with an automatic device to stop the drum after 200 revolutions.

3.2 *Sieves*—Square-mesh sieves having the following designations are needed: 2 in. (50-mm); 1½-in. (37.5-mm); ¾-in. (19.0-mm); ½-in. (12.5-mm); ⅜-in. (9.5-mm); ¼-in. (6.3-mm); and No. 30 (600-μm). The sieves shall conform to ASTM Specification E 11, for Wire-Cloth Sieves for Testing Purposes.[2]

3.3 *Scales*—The scales used for weighing the sample shall be sensitive to 23 g (0.05 lb).

3.4 *Riffle*, having a 38.1-mm (1½-in.) opening.

4. Preparation of Sample

4.1 *Sample Size:*

4.1.1 *Pellets*—Use a 11.3 ± 0.23-kg (25 ± 0.5-lb) sample of 38.1 by 6.35-mm (1½ by ¼-in.) pellets dried to constant weight of 105 to 110 C. Prepare by riffling the gross samples of pellets retained on the ¼-in. (6.3-mm) sieve to 11.3 kg (25 lb). The riffle should have 38.1-mm (1½-in.) openings.

NOTE 1—The gross sample collected shall be sufficient to obtain approximately 45.4 kg (100 lb) of pellets that will pass a 1½-in. (37.5-mm), and be retained on a ¼-in. (6.3-mm) square-mesh sieve. For pellets with more than 10 weight % larger than 12.7 mm (½ in.) the riffle opening should be three times larger than the largest single pellet to pass through the riffle.

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[1] This method is under the jurisdiction of ASTM Committee E-16 on Sampling and Analysis of Metal Bearing Ores and Related Materials.

Current edition approved Feb. 20, 1969. Originally published as E 279 – 65 T. Last previous edition E 279 – 65 T.

[2] *Annual Book of ASTM Standards*, Parts 14, 18, 26, 30, and 41.

4.1.2 *Sinter*—Use a 11.3 ± 0.23-kg (25 ± 0.5-lb) sample of 50.8 by 9.51-mm (2 by ⅜-in.) sinter. Prepare by taking proportionate weights of each size according to the screen analysis made by sieving the gross sample through 2-in. (50-mm), ¾-in. (19.0-mm), ½-in. (12.5-mm), and ⅜-in. (9.5-mm) sieves.

NOTE 2—The gross sample collected shall be sufficient to obtain approximately 45.4 kg (100 lb) of sinter which will pass a 2-in. (50-mm), and be retained on ⅜-in. (9.5-mm) square-mesh sieve.

5. Procedure

5.1 Place the 11.3-kg (25-lb) sample into the tumbler drum. Rigidly fasten the door and rotate the drum at 24 ± 1 rpm for a total of 200 revolutions. Then remove all of the material from the drum and hand sieve it on ¼-in. (6.3-mm) and No. 30 (600-μm) sieves. Separately weigh and record the amount of sample retained on the ¼-in. (6.3-mm) sieve, the amount retained on the No. 30 (600-μm) sieve, and the amount passing the No. 30 (600-μm) sieve. Mechanical sieving may be used, provided it has been established that the method gives the same results as hand sieving.

6. Number of Tests

6.1 At least two tests shall be made on each pellet sample. If the differences between the values obtained exceed 0.4 units in the cumulative percentage over the ¼-in. (6.3-mm) or the No. 30 (600-μm) sieve, at least one further test shall be made and the mean value of all tests taken.

6.2 At least two tests shall be made on each sinter sample. If the differences between the values obtained exceed 2.0 units in the cumulative percentages over the ¼-in. (6.3-mm) or the No. 30 (600-μm) sieve, at least one further test shall be made and the mean value of all tests taken.

6.3 The total loss in weight in any one test may not exceed 0.7 weight % of the initial sample weight. If the total loss in weight exceeds 0.7 %, the test shall be rejected.

7. Report

7.1 The sieve analysis after tumbler test shall be reported to the nearest 0.1 % as the percent on the ¼-in. (6.3-mm) sieve and the percent passing the No. 30 (600-μm) sieve.

8. Precision

8.1 No explicit statement of precision can be specified until such time as acceptable data become available.

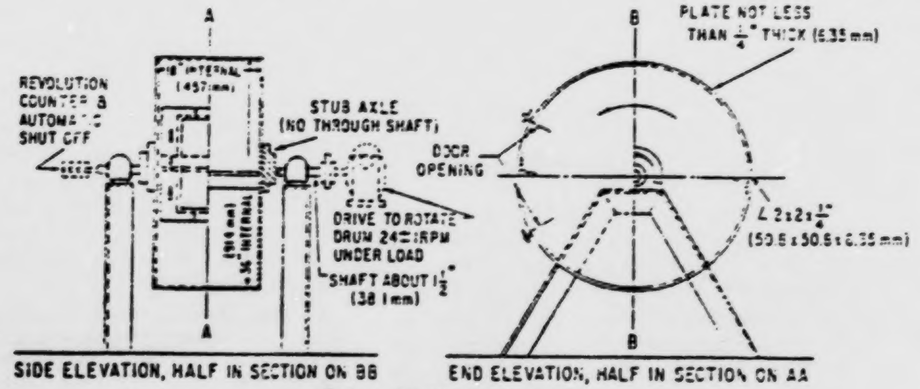
A
B
18" INTERNAL (457 mm)
REVOLUTION COUNTER & AUTOMATIC SHUT OFF
STUB AXLE (NO THROUGH SHAFT)
36" INTERNAL (914 mm)
DRIVE TO ROTATE DRUM 24±1RPM UNDER LOAD
SHAFT ABOUT 1½" (38.1 mm)
PLATE NOT LESS THAN ¼" THICK (6.35 mm)
DOOR OPENING
L 2x2x¼" (50.8x50.8x6.35 mm)
SIDE ELEVATION, HALF IN SECTION ON BB
END ELEVATION, HALF IN SECTION ON AA

FIG. 1 Tumbler Test Apparatus.

By publication of this standard no position is taken with respect to the validity of any patent rights in connection therewith, and the American Society for Testing and Materials does not undertake to insure anyone utilizing the standard against liability for infringement of any Letters Patent nor assume any such liability.

Fired Compression Strength

Crushing Strength - Samples of fired pellets are screened on 33/64 and 31/64 inch round hole screens. The -33/64 +31/64 inch diameter pellets are taken for crushing strength determinations. Twenty to fifty pellets are chosen from the -33/65 +31/64 inch fraction for crushing strength determination. Pellets having any form of cracking or spalling are not tested, if possible. The crushing strength is determined on a Tonindustrie Constant Load, Model 2705-398-1970, tested modified for ease of operation on pellets. The machine has a constant speed of approximately 1/4" per minute.

APPENDIX 4

Procedures for Determination of Metallurgical Properties of Fired Pellets

DRAFT PROPOSAL ISO/DP 4698

date 1983-04-29

ISO/TC 102/SC3N565E

supersedes document ISO/TC102/SC3N549E

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ISO/TC 102/SC3

Secretariat USA

Circulated to P- and O-members, technical committees and international organizations in liaison for :
- discussion at
- comments by 1984-08-31
- voting by (P-members only)

Title

Fourth Draft Proposal
IRON ORE PELLETS - DETERMINATION OF RELATIVE FREE-SWELLING INDEX

Introductory note

The first draft proposal for the determination of relative free-swelling index was written in 1974 (Doc. 3N288E). The document was reviewed at the seventh meeting of SC3 in Australia and the Secretariat prepared the second draft (Doc. 3N458E). At the ninth meeting of SC3 in Canada the delegates instructed the Secretariat to prepare the third draft which would include the comments submitted by Canada (Doc. 3N465) and Australia (Doc. 3N468). The third draft proposal was duly prepared and sent for comments to the Member Countries. Based on the comments received, the Secretariat prepared the fourth draft for discussion at the next SC3 meeting in Paris, France.

This is the fourth draft proposal.

ISO/TC102/SC3N4565E

April 1984

ISO/DP4698

FOURTH DRAFT PROPOSAL

IRON ORE PELLETS - DETERMINATION OF RELATIVE FREE-SWELLING INDEX

0 INTRODUCTION

The relative free-swelling index test method is one of several procedures used to evaluate the behaviour of iron ore pellets under specific conditions. The specific conditions involved in this test are: isothermal reduction; reduction in an unconstrained state; reduction by means of gaseous reductant; and a sample having a specified size range.

The results of this test should be considered in conjunction with the results of other tests, particularly those showing the physical behaviour of iron ore pellets during reduction.

1. SCOPE

This International Standard specifies a method for determining the relative free-swelling index of iron ore pellets.

2. REFERENCES

ISO 3310/1, Test sieves - Technical requirements and testing - Part 1: Test sieves of metal wire cloth.

ISO 3081, Iron ores - Increment sampling - Manual method.
ISO 3082, Iron ores - Increment sampling - Mechanical method.
ISO 3083, Iron ores - Preparation of samples.
ISO 2597, Iron ores - Determination of total iron content - Titrimetric method.

3. DEFINITIONS

For the purpose of this International Standard the following definition applies:

3.1 Swelling: A volume increase of iron ore pellets caused by reduction.

6. APPARATUS

Ordinary laboratory equipment, and

6.1. Electrically heated furnace, having heating capacity sufficient to maintain the entire test portion and the gas contacting it at 900±10°C.

Figure 1 shows an arrangement of the reduction test apparatus.

6.2 Reduction tube, made of non-scaling, heat-resistant metal to withstand a temperature higher than 900°C. The internal diameter of the reduction tube shall be 75 ±1 mm.

The reducing gas shall be preheated before entering the test portion, to maintain the test portion at 900±°C during the entire test period. To make this possible, the reduction container may consist of two tubes, an outer tube (105 mm diameter) and an inner one (75 mm diameter), the latter concentrically placed within the former. The inlet gas is delivered into the upper part of the outer tube and heated in the space between the two tubes, after which it flows up through the inner tube.

The sample holder shall be made of non-scaling, heat-resistant metal to withstand a temperature higher than 900°C. It shall have room for 18 pellets in the 10,0-12,5 mm size range.

Figure 2 shows an example of a reduction tube with a sample holder.

6.3 Weighing device, capable of weighing the test portion to an accuracy of 0,05 g. The senstivity of the weighing device shall be checked at regular intervals.

6.4 Device, capable of determining the volume of the test portion to an accuracy of 0,2 ml. Figure 1 shows an example of a device for measuring volume. Any other method for measuring pellet volume may be used, as long as it meets the accuracy of the standard.

6.5 Test sieves, conforming to test sieve standard specifications and having square mesh apertures of the following nominal sizes:

10,0 mm and 12,5 mm.

7. PREPARATION OF TEST SAMPLE

7.1 General

The test sample shall be prepared according to ISO 3083 from the sample for physical testing which has been taken in accordance with ISO 3081 or ISO 3082. The test sample shall be oven dried at 105±5°C and cooled to room temperature before testing.

CAUTION - Carbon monoxide and the reducing gas which contains carbon monoxide are toxic and therefore hazardous. During the following procedure, the testing shall be carried out in a well ventilated area or under a hood. Precautions, according to the safety codes of each country, should be taken for the safety of the operator.

Introduce the reducing gas to replace the inert gas at a flow rate of 15 l/min. and continue reduction for 60 min.

Record the loss of sample mass after reduction either before or after cooling.

After reduction cool the test portion under a flow of inert gas to room temperature by removing the reduction tube from the furnace and cooling the test portion under a flow of 5 l/min. of the inert gas.

Remove the test portion when cold from the reduction tube and weigh.

Determine the total volume of the test portion.

9. EXPRESSION OF RESULTS

9.1. Calculation of swelling index

Calculate the swelling index, ΔV, expressed as a percentage, using the following formula:

$$\Delta V = \frac{V_1 - V_0}{V_0} \times 100$$

where

V_0 is the volume of the test portion before reduction;

V_1 is the volume of the test portion after reduction.

Record the swelling index to one place of decimals.

9.2 Calculation of weight loss

Calculate the weight loss during reduction, ΔM, expressed as a percentage, using the following formula:

$$\Delta M = \frac{M_o - M_1}{M_o} \times 100$$

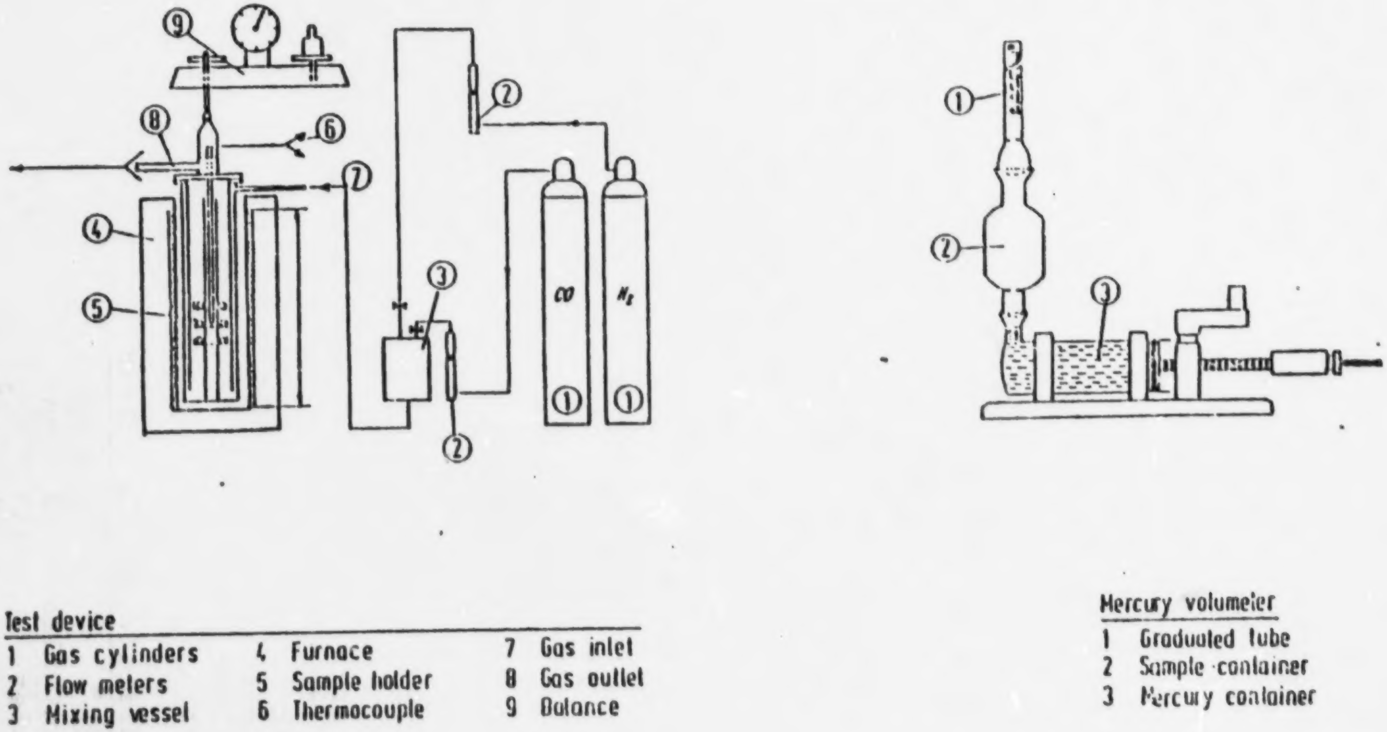
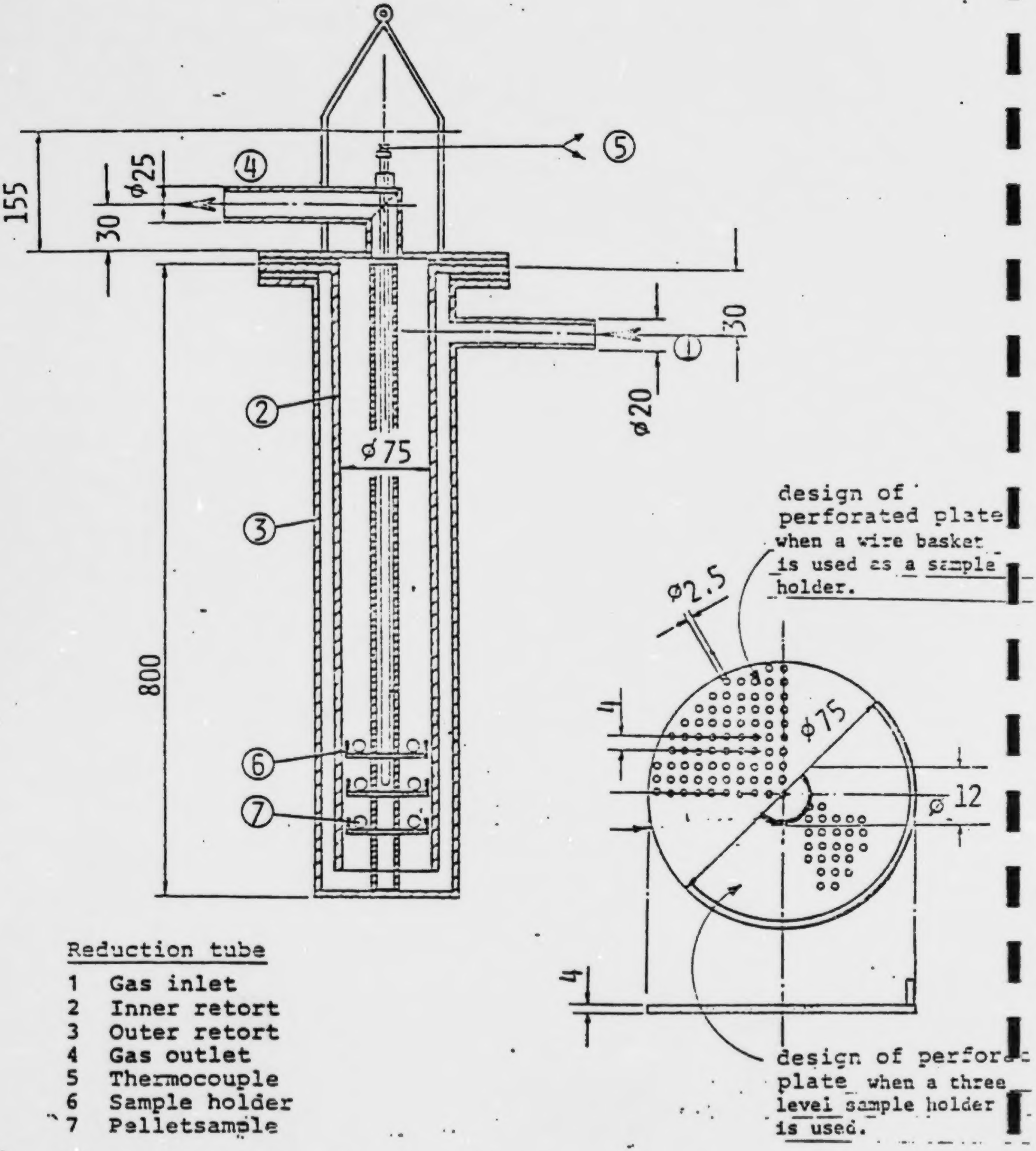

⑨
⑧
⑥
⑦
④
⑤
③
②
②
CO
N2
①
①
Test device
1 Gas cylinders
2 Flow meters
3 Mixing vessel
4 Furnace
5 Sample holder
6 Thermocouple
7 Gas inlet
8 Gas outlet
9 Balance
①
②
③
Mercury volumeter
1 Graduated tube
2 Sample container
3 Mercury container

Figure 1 Example of Reduction Test Apparatus and Equipment for Measuring the Swelling of Iron Ore Pellets



design of perforated plate when a wire basket is used as a sample holder.

design of perfor plate when a three level sample holder is used.

Reduction tube

1 Gas inlet
2 Inner retort
3 Outer retort
4 Gas outlet
5 Thermocouple
6 Sample holder
7 Pelletsample

Perforated plate / sample holder

Hole diameter	: 2.5	mm
Pitch between holes	: 4	mm
Number of holes	: 241	
Total hole area	: 11.8	cm^2
Thickness of plate	: 4	mm
Border	: 3x7	mm

Figure 2 Example of a Reduction Tube with Sample Folder

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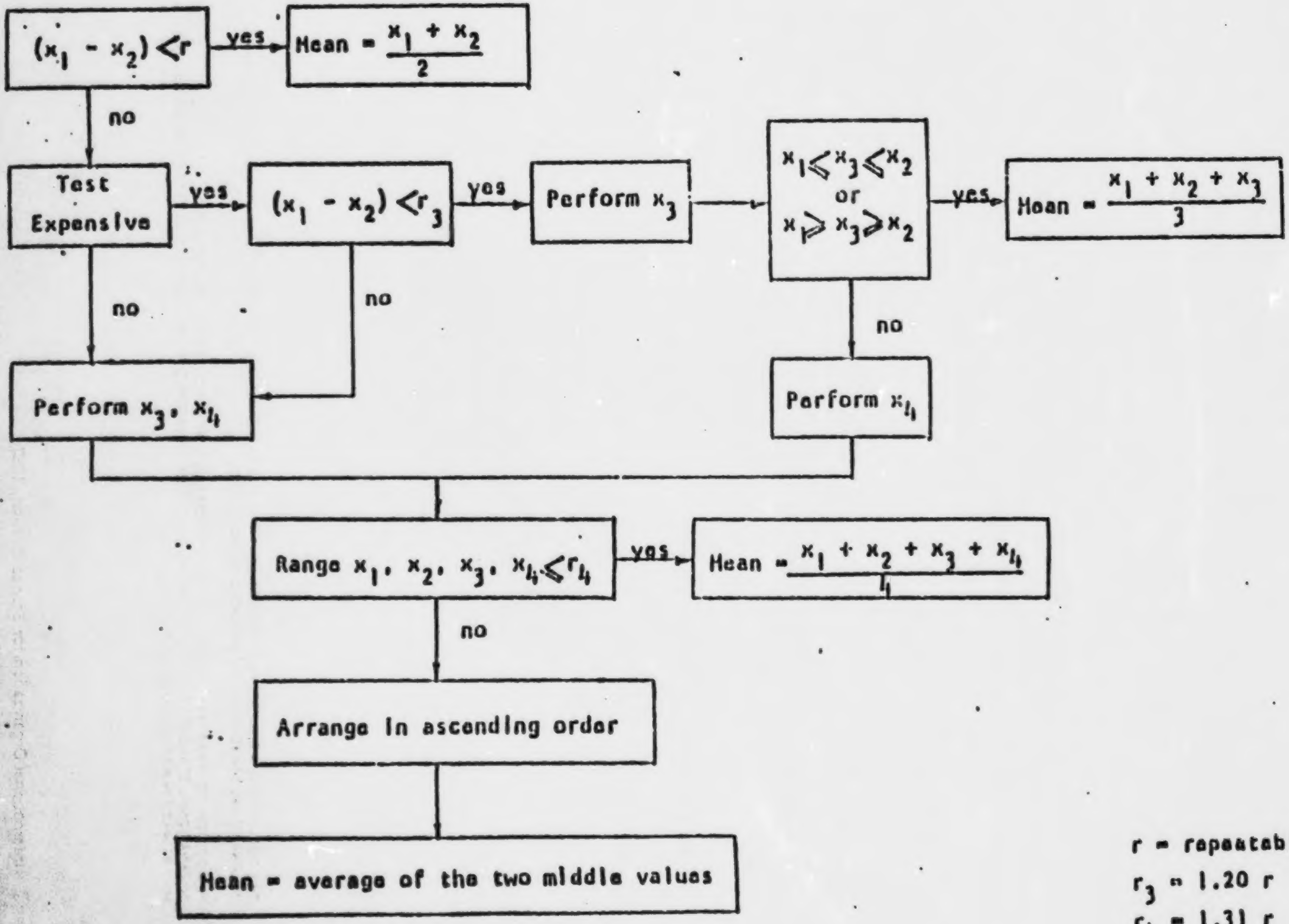
OF THE TEST RESULTS



$(x_1 - x_2) < r$
yes
Mean = $\frac{x_1 + x_2}{2}$
no
Test Expensive
yes
$(x_1 - x_2) < r_3$
yes
Perform x_3
$x_1 \leqslant x_3 \leqslant x_2$ or $x_1 \geqslant x_3 \geqslant x_2$
yes
Mean = $\frac{x_1 + x_2 + x_3}{3}$
no
no
Perform x_3, x_4
no
Perform x_4
Range x_1, x_2, x_3, $x_4 \leqslant r_4$
yes
Mean = $\frac{x_1 + x_2 + x_3 + x_4}{4}$
no
Arrange in ascending order
Mean = average of the two middle values

r = repeatability *
$r_3 = 1.20\ r$
$r_4 = 1.31\ r$

*Repeatability is the standard deviation within laboratories multiplied by 2.77

DRAFT INTERNATIONAL STANDARD ISO/DIS [illegible]

ISO/TC
102
Submitted on
1982-11-18

Secretariat
JISC
Voting terminates on
1983-05-18

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Iron ores — Determination of reducibility

Minerais de fer — Détermination de la réductibilité

UDC 553.31 : 620.1 : 669.173.2

Descriptors : metalliferous minerals, iron ores, tests, determination, reduction ratio.

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1 E M Karpinski
1 J S Kallmann

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DRAFT INTERNATIONAL STANDARD **ISO/DIS 4695**

Iron ores — Determination of reducibility

0 Introduction

The reducibility test method is one of several procedures used to evaluate the behaviour of natural and processed iron ores under specific conditions. The specific conditions involved in this test are: isothermal reduction; reduction in a fixed bed; reduction by means of carbon monoxide; and a sample having a specified size range.

The results of this test should be considered in conjunction with the results of other tests, particularly those showing the physical behaviour of materials during reduction.

The mathematical derivation of formulas for reducibility is included for information only in the annex.

1 Scope and field of application

This International Standard specifies a method for determining the reducibility expressed as reduction rate of natural iron ores and agglomerates such as pellets or sinters.

2 References

ISO 2597, *Iron ores — Determination of total iron content — Titrimetric method.*

ISO 3081, *Iron ores — Increment sampling — Manual method.*

ISO 3083, *Iron ores — Preparation of samples.*

3 Definition

For the purpose of this International Standard the following definition applies:

3.1 reducibility: A measure of the ease with which oxygen combined with iron can be removed from natural or processed iron ores with a reducing gas, which is expressed as the rate of reduction at an atomic ratio O/Fe = 0,9, relative to the iron(III) state.

4 Principle

Isothermal reduction of the test portion at a specified size range in a fixed bed, at a temperature of 950 °C using a reducing gas consisting of CO and N_2.

Weighing of the product at specified time-intervals.

Calculation of the degree of reduction relative to the iron(III) state and calculation of the rate of reduction at the oxygen/iron ratio of 0,9.

5 Test conditions

5.1 General

Gas volumes and flow rates used in this International Standard are as measured at a temperature of 0 °C and at atmospheric pressure (101,325 kPa).[1]

5.2 Composition of reducing gas

The reducing gas shall consist of

CO 40 ± 0,5 % (*V*/*V*)
N_2 60 ± 0,5 % (*V*/*V*)

5.3 Purity of reducing gas

Impurities in the reducing gas shall not exceed

---

[1] 1 mm Hg = 0,133 3 kPa; 1 atm = 0,101 325 MPa

H_2	0,2 % (*V*/*V*)
CO_2	0,2 % (*V*/*V*)
O_2	0,1 % (*V*/*V*)
H_2O	0,2 % (*V*/*V*)

5.4 Flow rate of reducing gas

The reducing gas flow rate shall, during the test period, be maintained at 50 ± 0,5 l/min.

5.5 Temperature of test

The test portion is reduced at a temperature of 950 °C.

The reducing gas shall be preheated before entering the test portion to maintain the test portion at 950 ± 10 °C during the entire test period.

6 Apparatus

The apparatus shall consist of the following

a) a system to supply and regulate the gases;

b) a reduction tube;

c) a weighing device to determine the oxygen loss at regular intervals;

d) an electrically heated furnace to heat the test portion to the specified temperature;

e) test sieves.

Figure 1 shows an arrangement of the reduction tube and the furnace.

6.1 Reduction tube, made of non-scaling, heat resisting metal to withstand temperatures of higher than 950 °C. The perforated plate is mounted in the reduction tube for supporting the test portion. The diameter of the sample bed shall be 75 ± 1 mm.

Figure 2 shows an example of the reduction tube.

6.2 Furnace, having a heating capacity sufficient to maintain the entire test portion and the gas entering the bed at 950 ± 10 °C.

6.3 Weighing device, capable of weighing the load to an accuracy of 1 g. The weighing device shall be checked for sensitivity at regular intervals.

6.4 Test sieves, conforming to test sieve standard specifications and having square mesh apertures of the following nominal sizes:

16,0 mm, 12,5 mm and 10,0 mm.

7 Preparation of test sample

7.1 General

In case of commercial test, the test sample shall be prepared according to ISO 3083, from the sample for physical testing which has been taken in accordance with ISO 3081. The test sample shall be oven dried at 105 ± 5 °C and cooled to room temperature before testing.

7.2 Sample for reducibility test

A quantity of test sample sufficient to provide at least five 500 g test portions shall be prepared as follows:

a) Pellets

The test sample in the size range of 10,0 mm to 12,5 mm shall be obtained by sieving and, after sieving, only pellets taken at random shall be used for the test.

b) Ore or sinters

The test sample in the size range of 10,0 mm to 12,5 mm shall be prepared as follows:

Screen the sample on a 12,5 mm sieve and carefully crush the plus 12,5 mm material until it all passes the 16,0 mm sieve. Combine all fractions and remove by sieving the plus 12,5 mm and the minus 10,0 mm material from the sample.

NOTE — The reducibility of iron ores is a function of the size range of the particles so that results obtained with this International Standard will relate only to material in the size range 10,0 mm to 12,5 mm. If the reducibility of an iron ore of a different size range is required, it shall be obtained by a separate reducibility test or by other means. Using the apparatus specified in this International Standard, iron ores with a maximum diameter greater than 16,0 mm shall not be tested.

7.3 Sample for chemical analysis

A 500 g test portion shall be reserved for the determination of total iron content and Fe(II) content.

8 Procedure

8.1 Number of determinations

Carry out the test generally in duplicate on one ore sample.

8.2 Other determinations

Simultaneously with the test, determine the Fe(II)[1] and, in accordance with ISO 2597, the total iron content.

---

[1] An International Standard for the determination of Fe(II) content is now in preparation, and until its publication the authentic standard in each country can apply.

8.3 Test portion

Weigh, to the nearest 1 g, approximately 500 g (± 1 particle) of the test sample (mass m_0).

8.4 Reduction

Place the test portion in the reduction tube so that the surface is even. In order to achieve a more uniform gas flow, a two-layer bed of porcelain pellets having a size range of 10,0 mm to 12,5 mm may be placed between the perforated plate and the test portion.

Close the top of the reduction tube. Insert the reduction tube into the furnace and suspend it from the weighing device centrally ensuring that there is no contact with the furnace or heating elements.

Pass a flow of inert gas through the reduction tube at a flow rate of approximately 25 l/min and commence the heating. When the temperature of the test portion approaches 950 °C increase the flow rate of the inert gas to 50 l/min. Continue the heating maintaining the flow of the inert gas until the mass of the test portion is constant (mass m_1) and the temperature is constant at 950 ± 10 °C.

CAUTION — Carbon monoxide and the reducing gas which contains carbon monoxide are toxic and therefore hazardous. During the following procedure, the testing shall be carried out in a well ventilated area or under a hood. Precautions, according to the safety codes of each country, should be taken for the safety of the operator.

Introduce the reducing gas to replace the inert gas at a flow rate of 50 l/min. Record the mass of the test portion at least every three minutes for the first 15 min and thereafter at 10 min intervals.

Terminate the reduction when the oxygen loss reaches 65 %. If, after four hours, this has not been achieved, the test may be stopped.

NOTE — If so desired, the test portion may then be cooled under a flow of inert gas to enable sample examination to be carried out.

8.5 Calculation of degree of reduction

Calculate the degree of reduction after time t, R_t, relative to the iron(III) state, as a percentage, by the following formula:[1]

$$\left[\frac{0{,}111\ [\mathrm{FeO}]}{0{,}430\,[\mathrm{Fe}]} - \frac{m_1 - m_t}{m_0 \times 0{,}430\ [\mathrm{Fe}]} \times 100\right] \times 100$$

where

m_0 is the mass, in grams, of the test portion;

m_1 is the mass, in grams, of the test portion immediately before starting the reduction;

m_t is the mass, in grams, of the test portion after reduction time t;

T_{Fe} is the total iron content, as a percentage by mass, of the test sample prior to the test, determined in accordance with ISO 2597;

FeO is the iron(II) oxide content, as a percentage by mass, of the test sample prior to the test and is calculated from the iron(II) content by multiplying it by a factor of 1,286.[2]

Prepare the reduction curve by plotting the degree of reduction R_t against time t.

9 Expression of results

9.1 Calculation of reducibility index

Read out from the reduction curve the time in minutes to attain degrees of reduction of 30 % and 60 %.

The reducibility index, expressed as the rate of reduction at the atomic ratio of O/Fe of 0,9[3], in per cent per minute, is calculated from the following formula:[1]

$$\frac{dR}{dt} = \frac{33{,}6}{t_{60} - t_{30}}$$

$$(\mathrm{O/Fe} = 0{,}9)$$

where

t_{30} is the time, in minutes, to attain a degree of reduction of 30 %;

t_{60} is the time, in minutes, to attain a degree of reduction of 60 %;

33,6 is the constant.

Express the result to two decimal places.

NOTE — In certain instances, a degree of reduction of 60 % is not attained in the test. In such cases, lower values may be accommodated by the following formula:

$$\frac{dR}{dt} = \frac{K}{t_y - t_{30}}$$

$$(\mathrm{O/Fe} = 0{,}9)$$

---

[1] The derivation of the formula is given in the annex.

[2] Oxide conversion factor FeO/Fe(II) = 1,286.

[3] The atomic ratio O/Fe = 0,9 means 40 % degree of reduction.

where

t_y is the time, in minutes, to attain a degree of reduction of y %;

K is the constant depending on y %:

If $y = 50$ % then the value of $K = 20,2$;

If $y = 55$ % then the value of $K = 25,5$.

9.2 Permissible tolerance and acceptance of test results

For a paired result, the two individual results shall be within ± 2,5 % of the mean value of the pair of results. The reducibility index reported shall be the arithmetic mean of a paired result rounded off to the nearest 0,01 %/min.

If the difference between the paired results does not meet the permissible tolerance, another duplicate test shall be carried out. The reducibility index reported shall be the arithmetic mean of the four results rounded off to the nearest 0,01 %/min.

out. The reducibility index reported shall be the arithmetic mean of the four results rounded off to the nearest 0,01 %/min.

10 Test report

The test report shall include the following information:

a) reference to this International Standard;

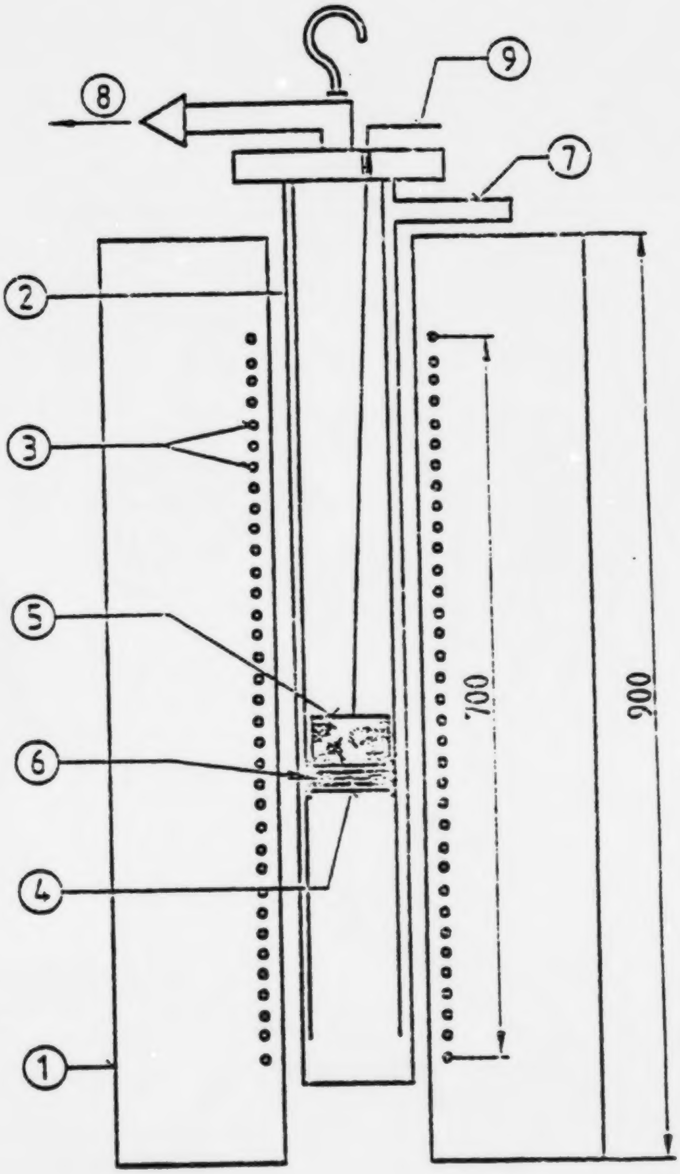
b) description of the test sample;

c) reducibility index;

d) total iron content and iron(II) content in the sample before reduction;

e) loss in mass versus time data if required.

Dimensions in millimetres

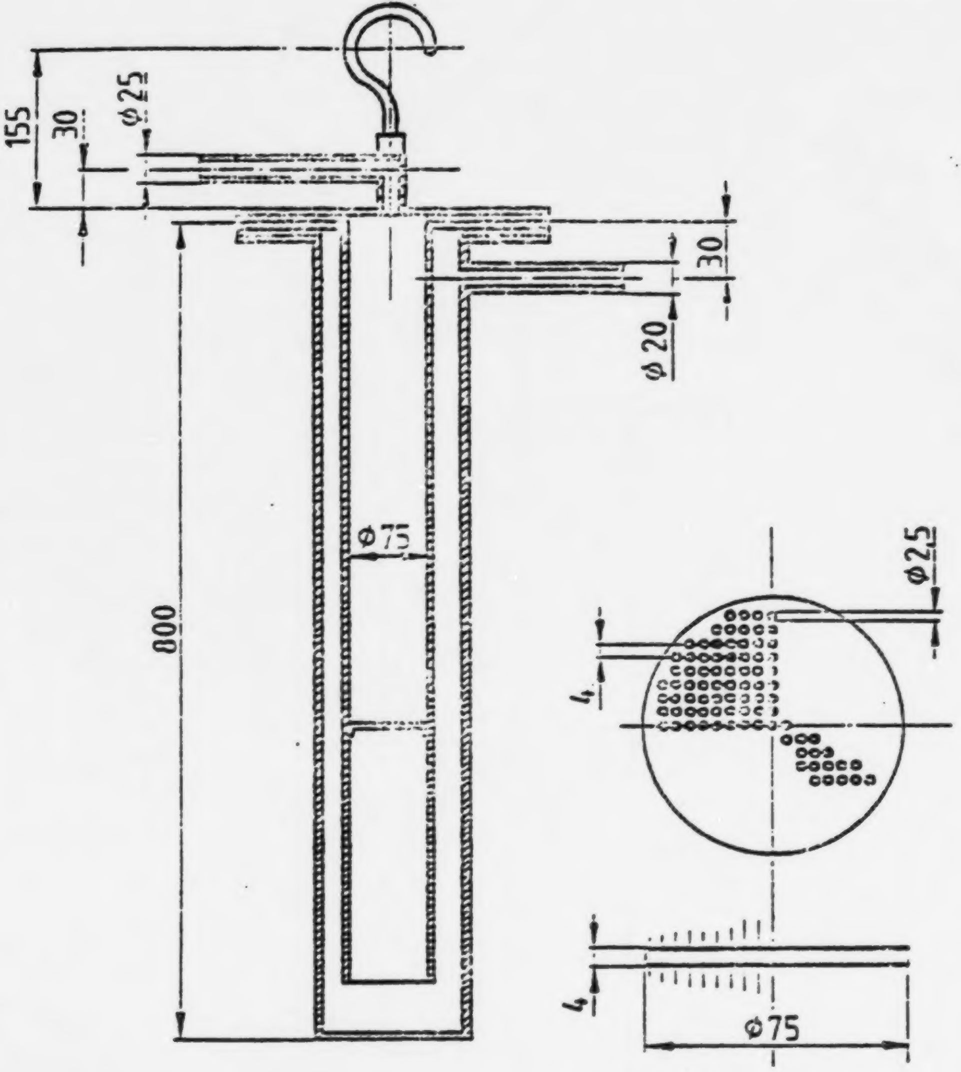


1. Furnace (10 kVA) (5.2)
2. Reduction tube (5.1)
3. Heating element
4. Perforated plate
5. Test portion
6. Layer of porcelain pellets
7. Gas inlet
8. Gas outlet
9. Thermocouple

NOTE — Dimensions are shown for information only.

Figure 1 — Example of test apparatus

Dimensions in millimetres


155
30
Ø25
30
Ø20
Ø75
800
Ø2,5
4
4
Ø75

Perforated plate

Hole diameter: 2,5 mm

Pitch between holes: 4 mm

Number of holes: 241

Total hole area: 11,8 cm^2

Thickness of plate: 4 mm

NOTE — Dimensions not specified in clause 6 are shown for information only.

Figure 2 — Example of reduction tube (6.1)

Annex

Derivation of formula for reducibility

(For information only.)

"Degree of reduction" describes the extent to which oxygen has been removed from iron oxides, and is defined generally as shown below:

$$\text{Degree of reduction} = \frac{\text{oxygen removed from iron oxide}}{\text{original oxygen combined with iron}} \qquad \ldots (1)$$

The formula in 8.5 is derived on the assumption that all oxygen combined with iron is present in the form of hematite (Fe_2O_3) whereas, for most iron ore materials, some magnetite (Fe_3O_4), wusite FeO, and metallic iron are also present. Therefore, the degree of reduction is estimated from the loss in mass of the test portion during reduction plus the difference between the theoretical oxygen content of the original sample, based on all iron being associated as Fe_2O_3, and the true oxygen content based on actual amounts of Fe_2O_3, Fe_3O_4 and FeO in the sample.

$$R_t = \frac{m_0\,[\mathrm{FeO}] \times \dfrac{8}{71{,}85}}{m_0\,[\mathrm{Fe}] \times \dfrac{48}{111{,}7}} \times 100 - \frac{m_1 - m_t}{m_0 \times \dfrac{[\mathrm{Fe}]}{100} \times \dfrac{48}{111{,}7}} \times 100 \qquad \ldots (2)$$

The formula in 8.1 is derived on the assumption that the rate of oxygen removed from iron ores is a first-order reaction with respect to the prevailing oxygen concentration.

$$-\frac{dO}{dt} = k \times O_v \qquad \ldots (3)$$

$$dO = -dR \times \frac{O_{total}}{100} \qquad \ldots (4)$$

$$\frac{O_v}{O_{total}} = 1 - \frac{R}{100} \qquad \ldots (5)$$

where

O_v is the prevailing oxygen content;

O_{total} is the total oxygen combined with iron (as Fe_2O_3);

R is the degree of reduction.

From equations (3), (4) and (5), the rate of reduction is derived:

$$\frac{dR}{dt} = k \times (1 - \frac{R}{100} \times 100 \qquad \ldots (6)$$

Integration of equation (3) gives

$$\log (1 - \frac{R}{100}) = -\,0{,}434\,kt + C$$

For R between 30 and 60 %,

$$k = \frac{-\log(1-60/100) + \log(1-30/100)}{0{,}434\,(t_{60} - t_{30})} = \frac{0{,}56}{t_{60} - t_{30}} \qquad \ldots (7)$$

In the case of hematite, the oxygen/iron ratio of 0,9 has the same meaning as R = 40 %. By substituting R = 40 % and equation (7) into equation (6), the value of $\mathrm{d}R/\mathrm{d}t$ (at O/Fe = 0,9) is obtained, i.e.

$$\frac{\mathrm{d}R}{\mathrm{d}t}\,(\mathrm{O/Fe} = 0{,}9) = \frac{33{,}6}{t_{60} - t_{30}}$$

DRAFT PROPOSAL ISO/DP 4697

date 1983-11-10

ISO/TC 102/SC3N555E

supersedes document ISO/TC102/SC3N286E

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ISO/TC 102/SC3

Secretariat USA

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- discussion at
- comments by 1984-04-30
- voting by (P-members only)

Title

Fourth Draft Proposal
Iron Ores - Method for Low Temperature Disintegration Test
- Tumbling During Reduction

Introductory note

The first draft proposal for this method was written in 1971 (Doc. 3N196E). The third draft proposal (Doc. 3N286E) was reviewed at the ninth meeting of SC3 in Ottawa, Canada and the delegates instructed the Secretariat to prepare the fourth draft proposal to align it with DP4696.

This is the fourth draft proposal.

ISO/TC102/SC3N555E
November 1983

ISO/DP4697
Fourth Draft Proposal

Iron Ores - Method for Low Temperature Disintegration Test - Tumbling During Reduction

0. Introduction

This International Standard describes one test method for evaluating the disintegration behaviour of iron ores reduced in a rotating tube under specific conditions relevant to the low temperature zone in the blast furnace for iron making. This method is a measure of the breakdown of blast furnace burden materials under conditions resembling those in the upper part of the blast furnace shaft.

The results of this test should be considered in conjunction with the results of other reduction tests, particularly those conducted at high temperatures.

1. Scope and Field of Application

This International Standard specifies a method for testing the disintegration of iron ores during reduction in a rotating tube at a temperature of 500°C.

This method is applicable to natural coarse iron ores and to iron ore agglomerates such as pellets or sinters.

2. References[1]

ISO 3081, Iron ores - Increment sampling - Manual method.
ISO 3083, Iron ores - Preparation of samples.

3. Principle

Reduction of the test portion with the specified size range in a rotating tube at the temperature of 500°C by reducing gas consisting of CO, CO_2 and N_2.

Cooling of the test portion, after 1 h reduction time, to a temperature below 100°C, and sieving with test sieves having square mesh apertures of 6,30 mm, 3,15 mm, and 500 µm.

---

[1] International Standards dealing with the reducibility, the relative reducibility and the relative free-swelling index of iron ores are in preparation.

Calculation of reduction-disintegration index (RDI), as a quantitative measure of the degree of disintegration of iron ores that have been reduced during tumbling; the percentage mass of material greater than 6,30 mm, greater than 3,15 mm, and less than 500 µm is related to the total mass of test portion before reduction.

4. Test Conditions

Volume and flow rate of gases used in this International Standard means those measured at a temperature of 0°C and at atmospheric pressure (101,325 kPa).[2]

4.1 Composition of Reducing Gas

The reducing gas shall consist of:

CO	20 ± 0,5% (V/V)
CO_2	20 ± 0,5% (V/V)
H_2	2,0 ± 0,5% (V/V)
N_2	58 ± 0,5% (V/V)

4.2 Purity of Reducing Gas

Impurities in the reducing gas shall not exceed

O_2	0,1% (V/N)
H_2O	0,2% (V/N)

4.3 Flow Rate of Reducing Gas

The reducing gas flow rate shall, during the test period, be maintained at 20 ± 1 l/min.

4.4 Temperature of Test

The reducing gas shall be preheated before entering the test portion to maintain the test portion at 500 ± 10°C during the entire test period.

---

[2] 1 mm Hg = 0,133 3 kPa, 1 atm = 0,101 325 MPa.

5. Apparatus

The apparatus shall consist of the following:

a. A system to supply and regulate the gases
b. A reduction tube
c. An electrically heated furnace to heat the sample to the specified temperature
d. Test sieves
e. A weighing device

Figure 1 shows an example of the arrangement of the reduction tube and furnace.

5.1 Reduction tube, made of non-scaling, heat-resisting metal to withstand a temperature of greater than 600°C. The internal diameter of the reduction tube shall be 130 mm and its inside length 200 mm. Four equally spaced lifters 20 mm wide and 2 mm thick shall be mounted longitudinally inside the reduction tube.

5.2 Furnace, having a heating capacity sufficient to maintain the entire test portion and the gas entering the tube at 500°C, and being equipped with a heating element suitable for the specified temperature.

5.3 Test sieves, having square mesh apertures of the following nominal sizes:

12,5 mm - 10,0 mm - 6,30 mm - 3,15 mm and 500 μm

5.4 Weighing device, of adequate load capacity and accurate to 0,1 g.

6. Preparation of Test Sample

In the case of a commercial test, the test sample shall be prepared according to ISO 3083 from the sample for physical testing which has been taken in accordance with ISO 3081. The test sample shall be oven dried at 105 ± 5°C for at least 2 h and cooled to room temperature before testing.

The total mass of the test sample shall be approximately 2 kg on a dry basis, being prepared as follows:

a. Pellets

The test sample in the size range of 10,0 mm to 12,5 mm, or other sizes as agreed between the parties concerned, shall be obtained by sieving and, after sieving, only pellets taken at random, for example by riffling, shall be used for the test.

b. Ore or Sinter

The test sample in the size range of 10,0 mm to 12,5 mm shall be prepared as follows:

Screen the sample on a 12,5 mm sieve and carefully crush the plus 12,5 mm material until it all passes the 16,0 mm sieve. Combine all fractions and remove by sieving the plus 12,5 mm and the minus 10,0 mm material from the sample.

7. Procedure

7.1 Number of Determinations

Carry out the test in duplicate on one ore sample.

7.2 Test Portion

Weigh, to the nearest 0,1 g, approximately 500 g (± 1 particle) of the test sample. The test portion should be obtained from the test sample either by means of riffle divider or by manual increment division method.

7.3 Reduction

Place the test portion (7.2) in the reduction tube (5.1). Insert the reduction tube into the furnace and connect the gas flow system to the reduction tube. Commence rotation of the reduction tube at 10 rpm.

Replace the air in the tube with inert gas. Heat the test portion and while heating pass a flow of inert gas through the reduction tube at a flow rate of approximately 20 l/min. Continue the heating, while passing inert gas until the test portion reaches the test temperature of 500 ± 10°C.

NOTE: Unless the characteristics of the furnace and thermocouple are very well known a period of about 15 min should be allowed for temperature equilibration at 500°C.

CAUTION: Carbon monoxide and the reducing gas which contains carbon monoxide are toxic and therefore hazardous. The reduction shall be carried out in a well ventilated area or under a hood and precautions, according to the safety codes of each country, should be taken for the safety of the operator.

Introduce the reducing gas (4.1) at a flow rate of 20 ± 1 l/min to replace the inert gas and to reduce the test portion. Continue the reduction with the reducing gas for 1 h.

After 1 h reduction time, stop the flow of the reducing gas and cool the test portion to a temperature below 100°C in the rotating reduction tube under a flow of inert gas.

7.4 Sieving

Remove the test portion carefully from the reduction tube, determine the mass (mass m_0) and hand sieve with care on 6,30 mm 3,15 mm and 500 µm sieves. Determine and record the mass of each fraction retained on 6,30 mm (mass m_1), 3,15 mm (mass m_2) and 500 µm (mass m_3). Material lost during sieving shall be considered to be minus 500 µm.

NOTE: Equivalent mechanical sieving may be used provided that preliminary test results give similar results to hand sieving within the permissible tolerance of 2% absolute.

8. Expression of Results

The reduction-disintegration index, RDl, as a percentage by mass, is calculated from the following formulae:

$$RDl_{+6,3} = \frac{m_1}{m_0} \times 100$$

$$RDl_{+3,15} = \frac{m_1 + m_2}{m_0} \times 100$$

$$RDl_{-0,5} = \frac{m_0 - (m_1 + m_2 + m_3)}{m_0} \times 100$$

where

m_0 is the mass, in grams, of test portion after reduction

m_1 is the mass, in grams, of oversize fraction retained on the 6,30 mm sieve

m_2 is the mass, in grams, of oversize fraction retained on the 3,15 mm sieve

m_3 is the mass, in grams, of oversize fraction retained on the 500 mm sieve

Repeatability and number of tests will be given in an annex.

9. Test Report

The test report shall include the following information:

a. Reference to this International Standard

b. Results of the test: reduction-disintegration indices expressed to one decimal place and results of all the tests

c. Identification of the sample

d. Sieving conditions, e.g., method of sieving, and sieving time

e. Gas composition used for tests

f. Any operation and any test conditions not specified in this Internatioonal Standard or regarded as optional which may have had an influence on the results.

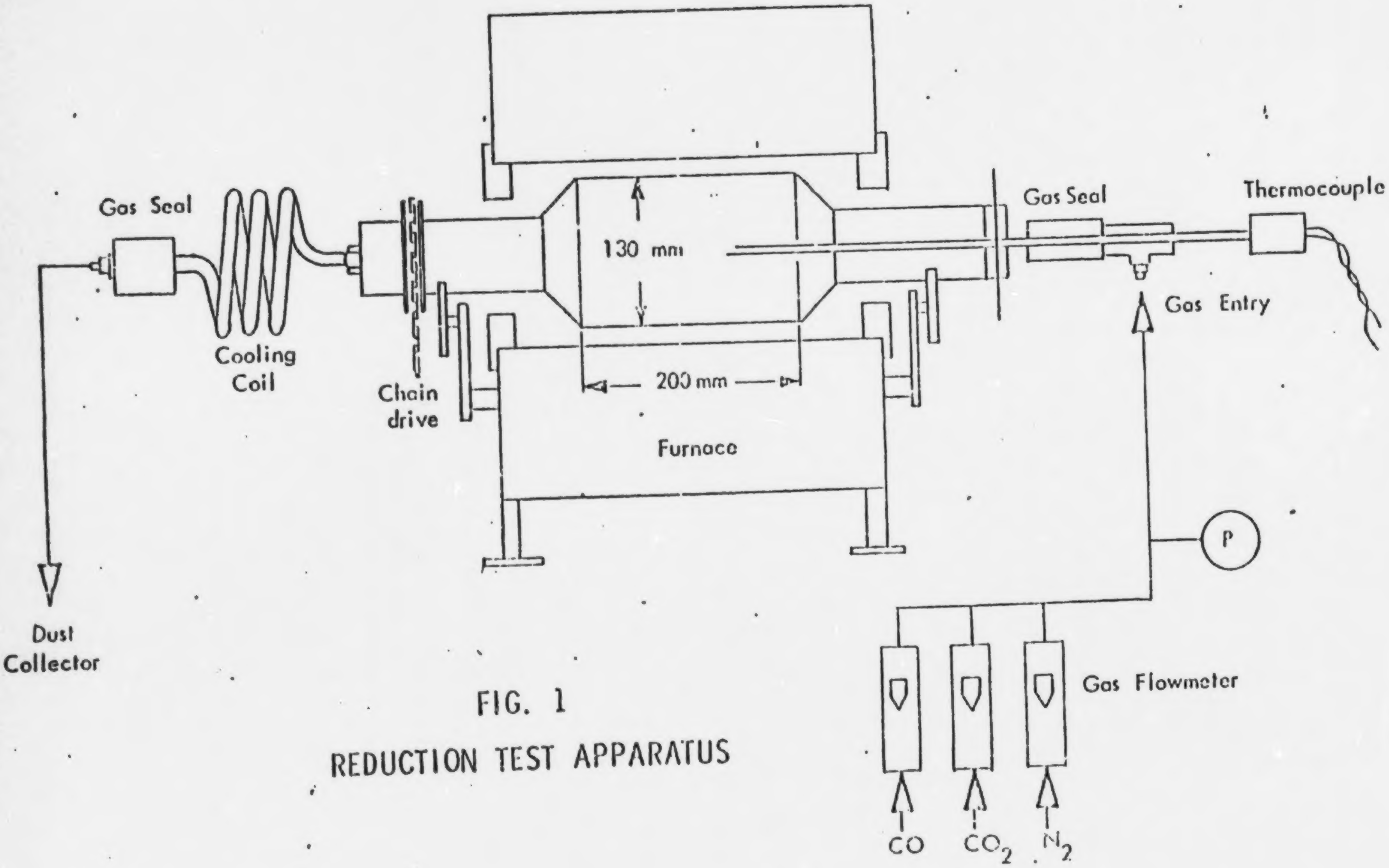

Gas Seal
Cooling Coil
Chain drive
130 mm
200 mm
Furnace
Gas Seal
Thermocouple
Gas Entry
P
Gas Flowmeter
CO
CO2
N2
Dust Collector

FIG. 1

REDUCTION TEST APPARATUS

APPENDIX 5

Report on Pot Grate Test Results

by Hanna Research Center

THE HANNA MINING COMPANY
RESEARCH CENTER
P.O. BOX 67
NASHWAUK, MINNESOTA 55769
(AREA CODE 218) 885-1551

April 30, 1985

MEMORANDUM NO. M-85-57

TO: R.D. Frans

FROM: D.J. Englund

SUBJECT: Project 548-432

Organic Binder Evaluation

Background: At the request of I.O.C., a series of pot-grate tests have been performed to evaluate the Peridur brand organic binder as a bentonite replacement. In addition, reported in Table 2 are results from some batchball tests conducted in January, 1985. The objective of this program was to determine a suitable addition level and define the impact of an organic binder on pellet quality.

Samples: The Peridur (84-212) was presently on hand. Seven drums of concentrate containing ±1% coke breeze were received from I.O.C. in February, 1985. The Greek bentonite (84-161) used in the baseline tests was left over from the 1984 fluxed pellet program.

Tests and Conditions: The standard plant firing cycle (cycle #1) was used to initiate the program. This cycle was typical of plant operation in the late fall of 1984. When the plant engineer arrived, it was explained that the standard plant cycle had been changed to optimize the system. This cycle was then tested in the remaining tests (cycle #2). Firing cycle #3 represents a cycle midway between 1 and 2. All tests were performed with a 12" greenball bed and a 4" hearth layer. No airflow data was taken, to conserve charges and meet the quoted price. In addition, pellet samples were split from the bed as a whole rather than from top and bottom half splits for pellet quality tests, to conserve charges against the project. The batchball tests were not authorized and were not charged against this project although they are reported in this report.

Results and Discussion: The results of the pot-grate tests are given in Table 1. Figures 1 and 2 illustrate some of the trends.

Greenball Properties: The greenball characteristics, given in Table 1, for pilot disc balled samples indicate that acceptable strengths could be produced with Peridur at 2.24 lbs/DLT conc. Batchball results as shown in Table 2 indicate acceptable strengths down into the range of 1.5 - 1.8 lbs/DLT conc.

Fired Pellet Properties: There appears to be a significant problem associated with the use of these binders. The results generated in Table 1 contained duplicate tests but at two moisture levels (8.4-8.5 vs. 8.8-9.0 % moist.). For low moistures (<8.5% wt.) the organic binders will produce acceptable fired pellet qualities (see 84 PGF 114,115,120). However, these tests were performed with firing cycle #1 which utilizes higher bed Δ P's than the plant currently operates at. Thus the fuel consumption most likely would increase if this cycle were used.

Above 8.5% moisture in the greenballs is where the problem begins. The organic binders due to their low dosage level (1-2 lbs./DLT) are not capable of immobilizing the condensed water in the upper portions of the bed during drying. As a result, a localized dissolution of pellets occurs resulting in a mud that plugs up the bed, significantly reducing gas flow for any given bed Δ P. The result is that the bottom 1/3 or so of the bed remains grossly underfired producing low compression strengths and high tumble abrasion values.

Several attempts were made to improve fired pellet quality in the higher moisture tests. These include low Δ P in firing zones, firing a 10" bed with a corresponding cycle time decrease for constant tonnage and an increased firing zone #2 temperature. These modifications did not significantly improve fired pellet quality.

Metallurgical testing of four selected samples showed an increase in reducibility, a decrease in LTD strength and an increase in the maximum swelling index. These trends are partly a result of the slightly underfired conditions in the bed. It is difficult to say how much of these changes were in fact caused by the organic binder.

Summary: Marginal fired pellet quality may be achieved with Peridur at the addition level of 3.36 lbs/DLT conc., if the current operating pressure drops are increased by 3-6 in H_2O. This will probably increase fuel consumption as well. (85-PGF-125).

If concentrate moisture could be kept below 8.5% wt., an addition of 2.24 lbs/DLT conc. of Peridur would produce acceptable pellets. However, the pressure drops will again have to be increased from present levels (85-PGF 120,121).

With the present firing conditions, an organic binder does not appear to be a viable alternative as a bentonite replacement. The present firing cycle was not tested with 0.10% Peridur at low moisture, although at 8.7% (85-PGF 124) one can see that quality has still been severely affected.

A conversation with Hercules Inc. sales personnel indicate an interest on their part to meet this challenge. If they provide a product for testing at a later date the testwork could be resumed.

DJ Englund

D.J. Englund

-DJE:dcc

cc: J.S.W. & 6 Copies for I.O.C.
A.R.Z.
D.D.C.
T.M.W.
F.W.K.
Pellet Room

TABLE 1
I.O.C. CAROL LAKE ORGANIC BINDER PROGRAM: POT GRATE TEST RESULTS

t o.	Description	Moist % Wt.	Wet Comp Str. lbs.	Dry Comp Str. lbs.	No. 18" Drops	Firing Cycle	Ave. Comp Str. lbs.	Struct. % Wt. +1/4"	Tumble % Wt. +1/4"	Tumble % Wt. -28M	Inter-face °F	Porosity % Void Vol.	ISO Red. R40	LTD % +1/4	HRC Free Swelling % Vol. Time Min: 15	30	60
PGP-112	0.8% Bent.(84-161) Baseline	9.3	3.7	23.5	19.7	1	618	99.6	95.6	4.2	2360						
PGP-113	0.8% Bent. Baseline	9.3	3.7	23.5	19.7	1	729	99.9	96.6	3.2	2395	30.8	0.65	99.3	15.3	15.5	15.2
PGP-128	0.8% Bent. Baseline	8.9	3.4	22.2	20.6	2	648	99.6	95.9	3.9	2290						
PGP-114	0.05% Peridur	7.7	2.3	5.3	3.7	1	-	-	-	-	2355						
PGP-115	0.05% Peridur	7.7	2.3	5.3	3.7	1	699	99.5	92.1	7.7	2350	28.6	0.88	97.2	19.2	20.8	18.6
PGP-116	0.05% Peridur	9.0	1.4	4.4	7.2	1	386	90.8	70.9	28.6	2230						
PGP-117	0.05% Peridur	9.0	1.4	4.4	7.2	1	-	-	-	-	1640						
PGP-118	0.10% Peridur	9.0	2.2	9.0	13.1	1	511	98.1	86.8	13.0	1765						
PGP-119	0.10% Peridur	9.0	2.2	9.0	13.1	1*	309	97.6	83.4	16.3	1810						
PGP-120	0.10% Peridur	8.5	2.6	11.0	8.3	1	718	99.3	93.6	6.3	2260	29.2	0.92	97.9	18.9	20.6	19.6
PGP-121	0.10% Peridur	8.5	2.6	11.0	8.3	1**	719	99.5	95.1	4.8	2340						
PGP-122	0.15% Peridur	9.0	3.0	20.7	17.6	1	647	95.6	93.5	6.4	2040	31.0	0.90	97.8	19.1	21.0	19.7
PGP-123	0.15% Peridur	9.0	3.0	20.7	17.6	2	474	98.9	84.7	15.0	1855						
PGP-124	0.10% Peridur	8.7	2.4	10.2	7.0	2	468	96.2	91.9	17.8	1350						
PGP-125	0.10% Peridur	8.7	2.4	10.2	7.0	3	621	99.2	91.8	8.1	2169						
PGP-126	0.10% Peridur	9.0	2.4	10.8	11.7	2*	367	88.1	71.5	28.0	475						
PGP-127	0.10% Peridur	9.0	2.4	10.8	11.7	2**	244	94.1	69.7	29.8	1150						

All tests with 12" greenball bed and 4" hearthlayer except as noted.

	Cycle #1		Cycle #2		Cycle #3	
Zone	Inlet Gas °F	Bed ΔP in H_2O	Inlet Gas °F	Bed ΔP in H_2O	Inlet Gas °F	Bed ΔP in H_2O
UDD	550	18	450	12	450	12
DDD	550	18	500	15	500	15
PH	1300	18	1300	15	1300	18
F1	1900	18	2050	15	2050	18
	2250	18	2050	15	2050	18
F2	2370	18	2350	15	2350	18
F3	2100	18	2050	15	2050	18
AF	1600	18	1550	15	1550	18
Cool	Amb	20	Amb	20	Amb	20

1* = Cycle #1 with UDD = 650°F DDD = 750°F

1** = Cycle #1 with DDD-AF = 20 in H_2O ΔP

2* = Cycle #2 with F2 = 2450°F

2** = Cycle #2 with 10" Bed

D.J.E.
4/15/85

TABLE 2

I.O.C. CAROL LAKE ORGANIC BINDER PROGRAM: BATCHBALL TEST RESULTS

Binder Conc.		Peridur 84-211 *84-160				Peridur 84-211 **85-20		
Addition Rate % Wt.		0.05	0.06	0.07	0.08	0.06	0.08	0.10
Lbs./DLT Conc.		1.12	1.34	1.57	1.79	1.34	1.79	2.24
Greenball Properties								
No. 18" Drops	8.5% Moist.	5.8	6.1	8.9	8.4	8.1	9.1	11.4
	9.0% Moist.	7.6	10.6	11.7	12.8	10.3	11.4	16.9
Wet Comp. Str. lbs.	8.5% Moist.	1.6	1.8	1.9	2.3	2.4	2.9	3.2
	9.0% Moist.	1.4	1.5	1.8	1.9	2.3	2.5	3.0
Dry Comp. Str. lbs.	-	3.7	4.5	6.1	7.2	7.4	10.6	12.1
Deformation @ 1 lb.	8.5% Moist.	8.5	6.9	8.5	8.5	6.5	6.3	6.5
	9.0% Moist.	11.0	10.9	10.4	9.5	7.6	6.9	7.4
% Fracture	8.5% Moist.	11.5	12.4	12.4	14.2	11.9	13.4	14.6
	9.0% Moist.	14.9	14.1	14.6	14.6	13.4	15.0	15.9
Concentrate		84-160		85-20				
Uncorrected Blaine		2090		2064				
Structure % Wt. Pass								
	150 Mesh	94.2		93.7				
	200	87.6		86.1				
	270	80.6		78.4				
	325	69.7		66.9				
Assay % Wt.	Fe_{tot}	65.95		65.35				
	Fe^{++}	9.55		5.30				
	SiO_2	4.45		4.63				
	Al_2O_3	0.31		0.09				
	CaO	0.54		0.53				
	MgO	0.31		0.30				
	LOI	+.39		-1.19				

*No coke in concentrate

**Concentrate contains Coke Breeze

D.J.E.
4/15/85

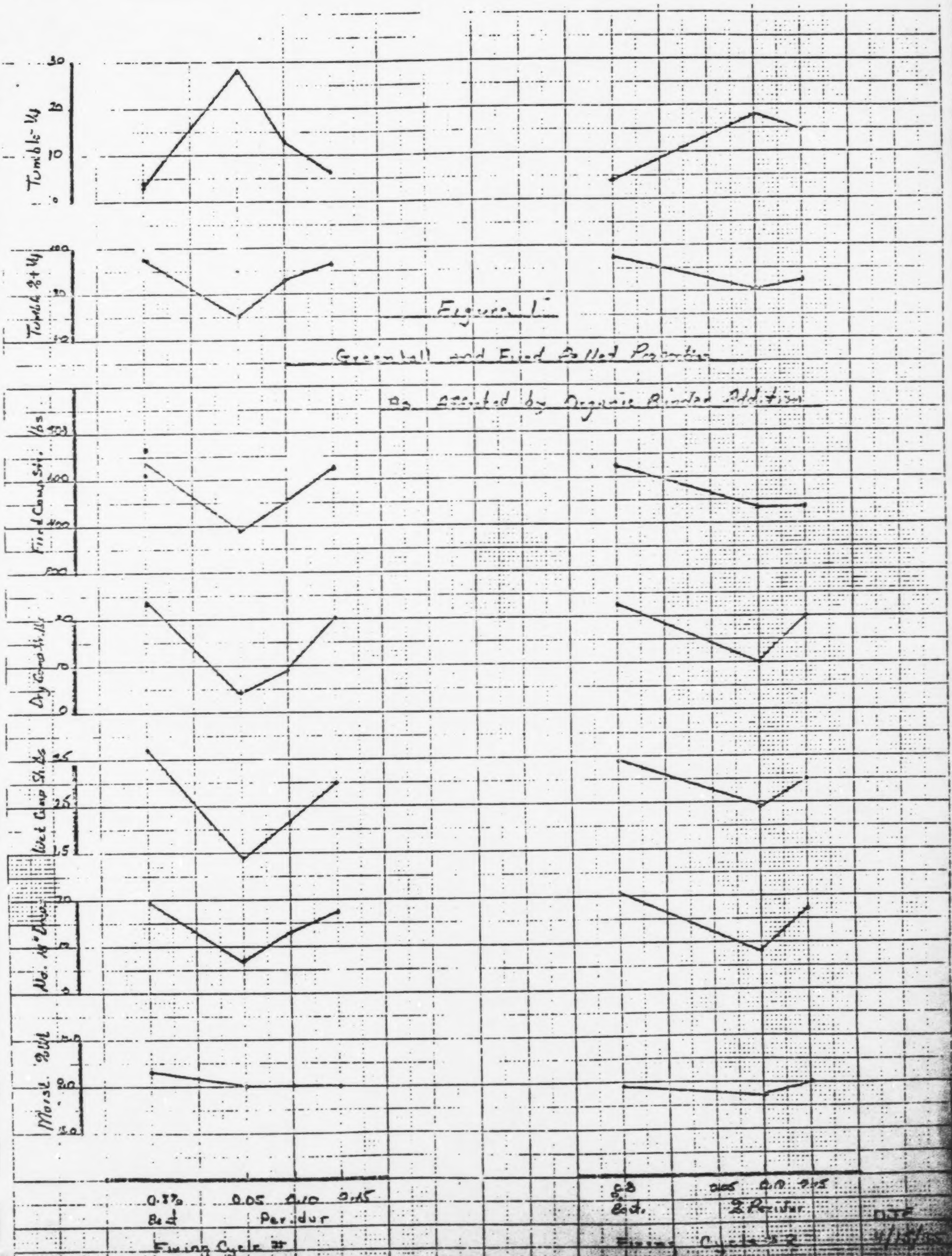


Figure 1

Greenball and Fired Pellet Properties

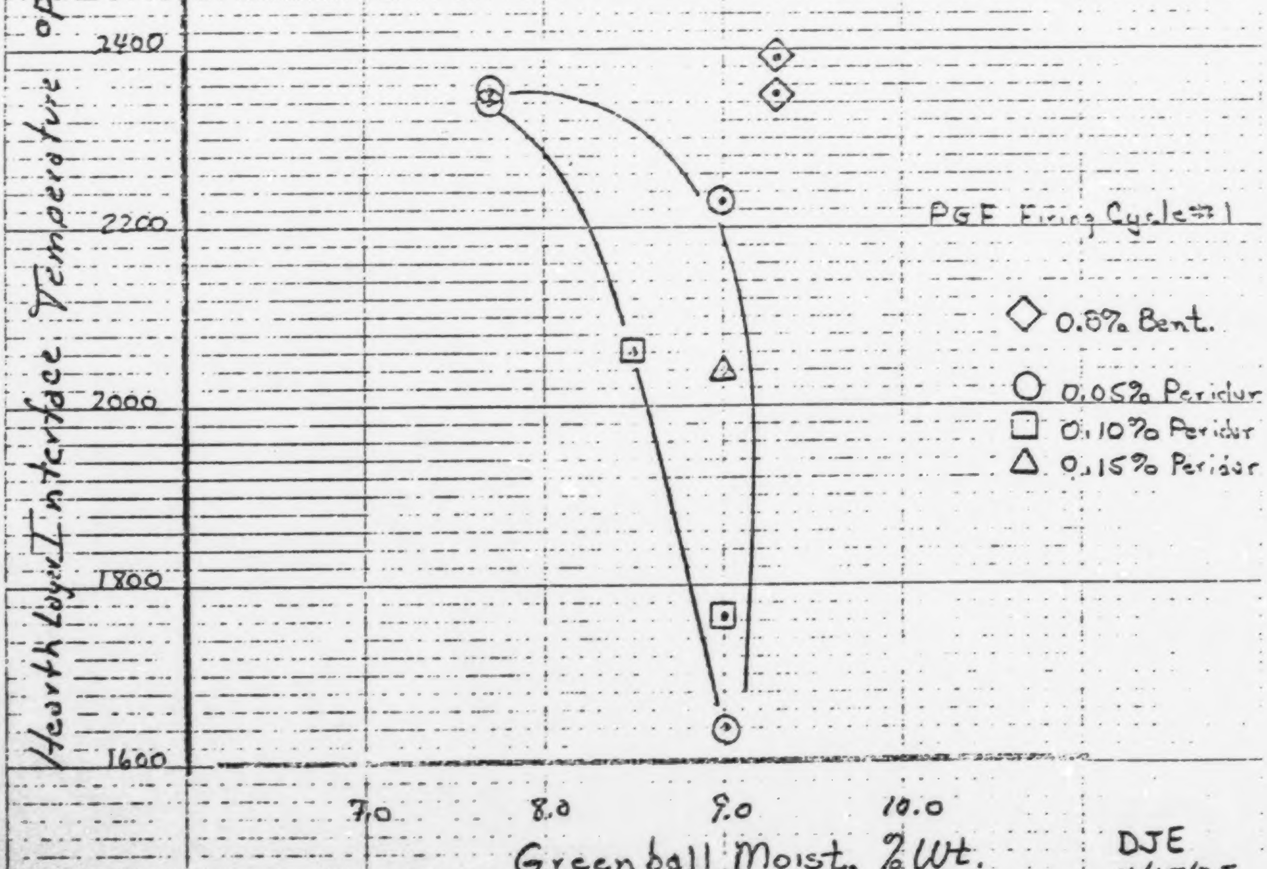
As Affected by Organic Binder Addition

Figure 2

Greenball/Hearth Layer Interface Temperature

VS

Greenball Moisture



DJE
4/15/85

APPENDIX III

PHASE III - FINAL REPORT

IRON ORE COMPANY OF CANADA

OFFICES — BUREAUX
SEPT-ILES, QUEBEC
MONTREAL, QUEBEC
SCHEFFERVILLE, QUEBEC
LABRADOR CITY, NEWFOUNDLAND — TERRE-NEUVE
ST. JOHN'S, NEWFOUNDLAND — TERRE-NEUVE

DEVELOPMENT OF A TECHNICALLY AND ECONOMICALLY ACCEPTABLE SUBSTITUTE BINDER FOR BENTONITE FOR USE WITH CAROL LAKE CONCENTRATE

PHASE III - FINAL REPORT

BY

TOM I. MARTINOVIC, P. ENG.

JUNE 06, 1986

WORK ON THIS PROJECT WAS CONDUCTED UNDER THE AUSPICES OF THE CANADA CENTER FOR MINERAL AND ENERGY TECHNOLOGY, ENERGY, MINES AND RESOURCES, CANADA

DSS FILE NUMBER:	03SQ.23440-4-9316
DSS CONTRACT NUMBER:	0SQ85-00053
CANMET SCIENTIFIC AUTHORITY:	J. M. D. WILSON, P. ENG.

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Appendix I CRM Report of 1986-02-17

Appendix II CRM Report of 1986-05-30

1.0 SUMMARY

Phase III of a study on development of a technically and economically acceptable substitute binder for bentonite for use with Carol Lake concentrate covered the evaluation of several potential binders in a laboratory and pilot plant - outside research facilities.

Centre de Recherches Minerales, Ministere de l'Energie et les Ressources, Quebec, was selected to carry out the testwork required for this phase.

This is a continuation of a program cosponsored by the Department of Supply and Services Canada and the Iron Ore Company of Canada. Reference should be made to DSS file number 03SQ.23440-4-9316.

Based on green ball quality achieved during tire balling testwork, among the several products investigated, Alchem 8C26 and peat moss showed potential as a bentonite substitute. As a result these two organic products were selected for further testwork. Alchem 8C26, a liquid anionic polymer, was supplied by Alchem Inc., Burlington, Ontario. Peat moss used was from the Quebec North Shore area and was supplied by Tourbieres Norbec Inc..

The evaluation of these two potential binders was carried out in a balling tire, 1 meter disc balling and firing in a pot grate machine. Balling test results showed that an acceptable green ball quality can be produced with both potential binders. The final series of pot grate tests was conducted with addition of 0.09% Alchem 8C26 as received. Peat moss was ground to approximately 50% less than 200 mesh and dried to 70% moisture content. The last series of pot grate tests was conducted with 0.5% of peat moss and 0.1% NaOH.

Pot grate test results showed that use of these two potential binders for acid pellet production will require further optimization to meet pellet quality requirements. Test results for fluxed pellets showed that an acceptable physical quality pellet can be produced, and very good metallurgical properties were obtained (reducibility 1.33 to 1.36 and LTD 95.4 to 96.7). It should be noted, that these results were obtained at somewhat lower green ball moisture level than current operating practice. With respect to the economics of these two potential binders, further testwork on optimization will be required to determine if desired pellet quality can be produced for acid pellet production.

There is good indication that peat moss has potential cost benefits as a bentonite substitute and partial or complete replacement of coke breeze.

It is recommended to carry out further laboratory and pilot plant testwork with Alchem 8C26 and peat moss to redefine technical and economical viability of these two potential binders.

The details on testwork and results for this phase are outlined in the attached reports provided by CRM, Appendix I and II.

2.0 INTRODUCTION

Phase III of a study on "Development of a technically and economically acceptable substitute binder for bentonite for use with Carol Lake concentrate" covers the evaluation of other potential binders in a laboratory and pilot plant test facilities.

Since this is a continuation of a program cosponsored by the Department of Supply and Services Canada and the Iron Ore Company of Canada a reference should be made to proposal DSS number 03SQ.23440-4-9316 and the reports for Phase I and IIA previously submitted.

The Phase III of the program covers the following scope of work:

1. Investigation of several products as a potential substitute binders for bentonite using the laboratory balling tire in order to select the two most suitable potential binders based on the balling characteristics and green ball quality achieved.

2. The scope of the second stage of Phase III covers the full scale pot grate test work on the two selected potential substitute binders. The full scale pot grate test work includes green ball production on 1 meter balling disc and pot grate firing to evaluate if desired pellet quality can be produced.

Centre de Recherches Minerals, Ministere de l'Energie et des Resources, Quebec, was selected to carry out the testwork required for Phase III.

3.0 PHASE III - TEST OBJECTIVES

The principal purpose of the Phase III of a program on development of a technically and economically acceptable substitute binder for bentonite for use with Carol concentrate was to evaluate several products in a laboratory and pilot plant facilities. In order to accomplish this, the following objectives were formulated:

3.1 Investigation of several products as a potential substitute for bentonite using the laboratory balling tire to determine if desired green ball quality can be produced.

3.2 Based on the green ball properties obtained with tire balling, two of the several products that showed good potential for bentonite substitution be selected for further testwork.

3.3 Evaluate the effect of these two potential binders on physical and metallurgical properties of fired pellets using pilot plant equipment, i.e. 1 meter balling disc and pot grate machine for pellet firing.

4.0 TEST PROCEDURES AND MATERIALS

4.1 TEST MATERIALS

In order to carry out the required testwork, the following materials were shipped to Centre de Recherches Minerales from the Carol Pellet Plant and other sources.

4.1.1 Iron Ore Concentrate

Several drums of a typical Carol Pellet Plant filtercake were collected. The filtercake also contained 8.8% moisture and 0.89% coke breeze which represents regular operating feed for green ball production.

The following shows the analyses of the filtercake:

% Fe	65.70
% SiO_2	4.58
% Fe_3O_4	46.00
% Moisture	8.8
Size % - 0.044mm	69.40

The filtercake for this shipment was used for laboratory tire balling and the initial disc balling and pot grate firing.

The second shipment of filtercake was required to complete the second stage of Phase III with the following analyses:

% Fe	64.80
% Sio_2	4.82
% Fe_3O_4	36.80
% Moisture	8.80
Size % - 0.044 mm	66.50

The coke content in this filtercake was 1.09%.

4.1.2 Bentonite

The processed bentonite (ground and dried at the Carol Pellet Plant) was shipped to CRM . Bentonite was required for the baseline tests. The laboratory balling was carried out with Wyoming bentonite while the remainder of the testwork was carried out with Greek bentonite.

The bentonite regularly used at the Carol Pellet Plant is the Greek product supplied by Silver & Baryte Ores Mining Company, Milos, Greece. The typical analyses of Greek bentonite are as follows:

Fe	3.60%
Mn	0.08%
SiO_2	60.42%
Al_2O_3	18.33%
CaO	2.01%
LOI	6.24%
Na_2O	3.10%
K_2O	1.94%
MgO	2.95%
$CaCl_2$	0.27%
S	0.44%
Plate index	684
Moisture	8.5%
Size	80% - 200 mesh

4.1.3 Potential Binders

The following potential binders were provided and shipped to Centre de Recherches Minerales by various suppliers.

Alchem 8C26 and 85030
Peat moss
Peridur
Hercules 6-CTL
Procell
Lignosol
Burnt lime
Quick lime
Sodium Silicate

These products were used as additives to the filtercake as received except for procell and peat moss which in some tests were reground.
For details on these potential binders see reports provided by Centre de Recherches minerales.

4.1.4 Dolomite and Limestone

Dolomite and limestone used for fluxed pellets tests were already available at CRM. These two materials were also ground to the required fineness during earlier testwork.

4.2 PREPARATION OF MATERIALS

4.2.1

For preparation of materials for the first stage of Phase III testwork, refer to CRM report of February 17, 1986.

4.2.2

As mentioned earlier, the second stage of testwork covered a pilot plant 1 meter disc balling and pot grate firing. The following summarizes the test procedure used for a full-scale pot grate testwork.

The preparation of materials:

a) The blending of filtercake (Carol Pellet Plant filtercake received in drums) was done by dumping them on the floor and mixing them manually in order to produce a homogeneous mix.

b) Bentonite and coke breeze (when required to balance the internal heat, magnetite-coke) were added and mixed in a dustless - rotary blender for a period of two minutes.

c) For preparation and addition of other potential binders refer to CRM report attached.

d) Balling was done on the one meter balling disc with the operating parameters to produce green pellet properties similar to the properties achieved in the balling drum at the Carol Pellet Plant.

e) For shredding of lumps created during mixing of concentrate and additives, the P-Kay mixer on the feed conveyor to the balling disc was used.

f) Pellet firing (induration) was performed in a Dravo type experimental pot grate machine. It should be noted that CRM made several modifications on this pot grate machine in order to improve control capability and better simulate the commercial plant pelletizing furnace.

4.3 BALLING - TEST PROCEDURE

4.3.1

The first stage of Phase III involved laboratory tire balling in order to evaluate various potential binders. The detailed balling test procedure is shown in the CRM report of February 17th, 1986. Also a photograph of the balling tire is shown on page 5 of the same report.

4.3.2

The second stage of Phase III testwork consisted of a pilot plant disc balling and pot-grate firing.

The balling feed as already described in section 4.2 was prepared in a dustless-rotary blender. The balling mix was discharged into the balling disc table feeder. The balling disc feed conveyor is equipped with a P-Kay mixer for shredding of lumps created during mixing operation. The balling feed rate was in the range of 200 to 275 kg/h depending on type of pelletizing mix. The balling was carried out until a sufficient amount of green balls were produced for two or three pot-grates. The typical operating parameters for the balling disc were; slope 45°, speed 15 rpm.

The balling disc angle, feed location, water and spray pattern were adjusted according to the balling characteristics of the balling mix. On-size fractions of the green balls were obtained by automatic screening at the disc discharge. The green balls were collected in 2.5 gallon pails and covered with wet paper towels. In addition these pails were covered with a plastic to prevent drying of green balls before being used for pot grate firing. The test samples of green balls for moisture, drop number, wet and dry compressions were taken according to the standard practice.

4.4 POT-GRATE - TEST PROCEDURE

The green balls (green pellets) were fired in a modified and improved Dravo type pot-grate machine. The pot charged with the green balls to be fired is approximately 0.35 meters in diameter. The pot grate instrumentation consists of thermocouples at various locations in the pot, indicators for airflows and pressure drop across the bed, controls and indicators for the incoming air temperature, burner controls and calibrated orifice plates and venturi meters for measuring the propane and airflows to the station.

An oxygen injection system is used to control the level of oxygen in the combustion products to the pellet bed in the downdraft preheating and firing zones. This is done to simulate commercial plant steady-state conditions where the secondary air at 1300-1500°F is utilized.

A digital process reporter is used for continuous recording of temperatures and pressure profiles.

In a pot that has an area of only 0.1 m^2, side effects can be severe and the pellets near the edge of the pot are not always adequately fired. This problem is overcome in a commercial plant by the use of side layers of fired pellets. To minimize this effect, CRM procedure involves rejection of edge layer by means of collecting these pellets seperately with vacuum cleaners. A second vacuum cleaner is used to unload the "good pellets" for evaluation.

The hearth layer (4") is used in the pot grate pot to provide protection for the grate bars. 12" of green pellets were charged on the top of the hearth layer forming the total bed of 16". The same bed configuration is used at the Carol Pellet Plant. The 12" pellet bed was separated in two portions (top and bottom part) for fired pellet quality determination. The screen was used to separate hearth layer from the fresh green balls. Also, a small portion of the screen was used in the middle of the green balls to easily detect the center when discharging the pellets in the two separate portions (top and bottom).
During the pot unloading pellets were visually inspected for possible spalling, cracks, slagging, unfired pellets etc. For additional details on disc balling and pot grate firing see the report of 1986-05-30 provided by CRM.

The baseline tests with bentonite and other potential binders were carried out on a potgrate machine using the firing cycle identical to the firing cycle used at the Carol Pellet Plant. The time/zone cycle for the pelletizing machines Nos. 5 and 6 were used, which is illustrated as follows.

ZONE	NO. OF WINDBOXES	TIME/ZONE MIN-SEC	CUMULATIVE TIME MIN-SEC
Updraft Drying	7	5'29"	5'29"
Downdraft Drying	3-½	2'44"	8'13"
Preheat	2-½	1'58"	10'10"
Firing 1A	4	3'08"	13'18"
1B			
Firing 2A	4	3'08"	16'26"
2B			
Firing 3	4	3'08"	19'33"
Afterfiring	5	3'55"	23'28"
Cooling 1	13	12'30"	36'00"
2	3		

TEMPERATURE AND PRESSURE PROFILES-REGULAR FIRING CYCLE

ZONE	TEMPERATURE, °F	PRESSURE, ΔP "W.C.
UDD	500	18
DDD	500	18
PH	1400	18
F-1A	1950	18
1B	2300	18
F-2A	2300	18
2B	2150	18
F-3	1900	18
AF	1600	18
Cool 1	Heat recuperated	20
2	from fired pellets	20

In addition to the regular firing cycle, changes were made to the temperature profile, pressure drop and bed depths in order to optimize pellet firing and improve pellet quality.

4.5 PELLET QUALITY-TEST PROCEDURES

The evaluation of green ball quality was carried out by determination of the following green ball properties:

- moisture content
- drop number
- wet compression
- dry compression
- size structure

The determination of these properties was done according to standard procedures.

The fired pellets were evaluated for the following:

a) Physical properties:
  - Tumble index
  - Fired compressions
  - Size structure

b) Metallurgical properties
- Porosity
- Swelling
- Reducibility
- Low Temperature Disintegration
- High Temperature Softening

It should be noted that the metallurgical tests were carried out only on pot grate pellets that showed the best fired pellet quality for a particular pelletizing mix (type of binder).
The test procedures for fired pellet quality determination are shown in Report on Results of Test Phase IIA, previously submitted.

The following pellet quality quidelines were used during the testwork:

Size structure:	+ 19.0mm	0 %
	+ 12.5mm	10 % max
	- 12.5 + 9.5mm	80 % min
	- 9.5 + 6.3mm	8 % max
	- 6.3mm	2 % max
Tumble index:	(+ 6.3mm)	96.0 ± 0.5
	(- 0.85mm)	4.0 ± 0.5
Fired Compressions:		
	Average	230 kg
	2 sigma deviation	115 kg
	- 90 kg	5 % max
Silica:		5.0 ± 0.2 %
Reducibility (R40)		0.8 % /min
Swelling		20 % max
Low Temperature Disintegration		90 % min

5. TEST RESULTS AND DISCUSSION

5.1 LABORATORY BALLING - TEST RESULTS

Test results for the first stage of Phase III covering the investigation of several products as potential substitute binders for bentonite using the laboratory balling tire are outlined in the report of February 17th, 1986 provided by CRM.
The test results indicated the following:

a) The green ball quality obtained with 0.8% Wyoming bentonite addition showed typical properties when using bentonite as a binder. The results of this test were used as the baseline for comparison.

b) A wide range of addition rates for various products as potential binders were tested. Among the several products tested, only four showed a potential for bentonite substitute.
These are: Alchem, peat moss, peridur and Hercules 6-CTL.

c) An organic binder, Alchem 8C26 at 0.125% addition rate with green ball moisture of 9.6% was selected for further tests based on green ball properties achieved at various levels of two Alchem products tested.

d) Peat moss was selected as the second product for further tests. Good tire balling was achieved at 1.0% (dry basis) addition rate with 0.2% NaOH and 10% green ball moisture level. Ground peat moss at 70%-200 mesh and 70% moisture content was used for the selected balling condition.

e) The other two binders that produced acceptable green ball quality Peridur and Hercules 6-CTL. Since these are very similar products and testwork on peridur as a potential binder was completed and reported in Phase IIA, further testwork on these two products was not pursued.

f) Using the combination of 0.3% peat moss and 0.1% Alchem produced good green ball quality.

5.2 POT-GRATE-TEST RESULTS

Two products, Alchem 8C26 and peat moss, were selected as the most suitable potential substitute binder based on tire balling test results.
Therefore, the scope of the second stage of Phase III covers the pilot plant balling on the 1 meter balling disc and the pot-grate firing to determine if desired pellet quality can be produced using these two binders. The pot grate test results showed the following:

a) Initial pot-grate testwork included the baseline test with bentonite, which is used for comparison. Several pot grate tests were carried out with Alchem 8C26 and peat moss. See test results in CRM report.
The test results of these pot grate tests showed that further optimization of green ball production was necessary in order to meet fired pellet specification.

b) Additional tire balling tests were carried out in order to optimize addition rates and balling characteristics of Alchem and peat moss.
In addition to tire balling testwork with Alchem 8C26, balling optimization was also carried out on the 1 meter balling disc. CRM designed and installed a system to add Alchem directly on the balling disc, thus bypassing mixing in a blender and P-Kay mixer operation. With an addition rate of 0.09% of Alchem as received a good quality of green balls was achieved.
Laboratory tire balling established that an acceptable green ball quality can be produced with 0.5% peat moss (dry) and 0.1% NaOH. These balling parameters were used for further pot grate tests.

c) Four pot grate tests were carried out with Alchem 8C26 at an addition rate of 0.09%. In spite of the fact that good balling was achieved, an acceptable physical quality of fired pellets was not produced. Modifications to the firing cycle were made, but pellet quality could not be improved with this addition rate and acid pellet chemistry.

d) Three pot grate tests were done with peat moss addition of 0.5% and 0.1% NaOH. Peat moss was ground to about 50% less than 200 mesh and dried to moisture content of 70%.
Due to low moisture in the filtercake, the drop number was only 4.0, while wet and dry compression showed good results. An acceptable fired pellet quality was not produced. It is believed that peat moss combined with coke breeze (0.5% peat moss plus 1.09% coke breeze) as an internal heat was excessive. The heating value of peat moss is about 8,000 to 11,000 Btu, which is close to that of coke breeze. Therefore, it became evident that the pellets produced with the peat moss as a binder will require less coke breeze addition. Therefore, peat moss offers double benefits, i.e. as a substitute binder and coke breeze replacement. Here again, modifications to the firing cycle were made to compensate for excessive internal heat, but it was not possible to prevent overfiring.

Since the filtercake, without coke breeze, was not available,no further work on acid pellets was carried out with these two potential binders.

Because further optimization of peat moss addition was not feasible, it was decided to carry out the remainder of the pot grate testwork on fluxed pellets.
6.0% dolomite and 4.0% limestone was added to the filtercake to produce pellet chemistry of $CaO/SiO_2 = 0.9$ and $MgO = 1.8\%$ which represents plant fluxed pellet production.

Alchem addition of 0.09% was used and two pot grate tests were carried out. An acceptable green ball quality was achieved. Tumble index of 4.7 and a fired compressions of 255 kg/p were achieved. Metallurgical properties achieved were very good. Porosity of 33.2%, swelling 11.8, reducibility 1.33 and LTD 96.7 were obtained. It should be noted that green ball moisture for these tests was 8.5%. These results indicate that further optimization may be possible to produce an acceptable quality of acid pellets as well.

f) Peat moss addition of 0.5% (dry) and 0.1% NaOH was used with fluxed pellets. In spite of low green ball properties and high excessive internal heat (0.5% peat moss vs 1.09% coke breeze), a tumble index of 4.6 and a fired compression of 202 kg/p were produced. Metallurgical properties were very good and typical for fluxed pellets with bentonite addition. Reducibility of 1.36, porosity 30.7%, swelling 13.5 and LTD 95.4 were obtained. It appears that lower internal heat, i.e. peat moss and coke breeze combined could produce an acceptable physical and metallurgical quality of pellets. Similar results were obtained during the pot-grate testwork on fluxed pellets carried out in 1984 when coke breeze addition was increased to offset calcination reactions of flux. Green ball moisture was 8.6% for optimum pot. For the details of the test results see CRM report.

g) With respect to the economics of using these two potential binders the test results indicated the following:
   - Use of peat moss as a potential substitute binder and partial or total replacement of coke breeze could provide significant cost benefits providing further testwork will redefine that an acceptable pellet quality can be produced. Current estimated cost for peat moss is $20/t FOB Port Cartier for small quantities. Larger orders should result in a lower unit cost.
   - Similarly, Alchem 8C26 as a potential binder can be evaluated from the economical point of view only after additional testwork is done on optimization and effect on physical and metallurgical quality. Current price for this product is estimated at $1.50/kg for small orders.

   It should be noted that an identical product to Alchem 8C26 is used at the Whyalla Pellet Plant, South Australia. It has fully replaced bentonite since April 1985. Because their flow sheet employs dry grinding, this organic binder is added directly in a balling circuit, where about 50% water is added. The addition rate is only 0.1 kg/t pellets.

It appears that dry grinding, finer material and different type of ore at the Whyalla Pellet Plant allows very low addition rate and high dilution of the binder which is very important for proper dispersion. Extrapolating this consumption rate and the Canadian cost of this product would provide significant economic benefits providing its technical feasibility can be proven and the addition rate is reduced.

6.0 CONCLUSIONS AND RECOMMENDATION

The test results of Phase III revealed the following:

1. Laboratory tire balling test results showed that among several potential binders tested, Alchem 8C26 and peat moss have good potential for bentonite substitution. Based on green ball quality achieved, these two potential binders were selected for pilot plant testwork.

2. Initial pot grate testwork using a 1 meter balling disc for green ball production and pot grate machine for pellet firing was carried out with the addition of 0.125% Alchem 8C26 as received and 1.0% (dry) peat moss with 0.15% NaOH respectively. Peat moss was ground to about 30% less than 200 mesh and dried to 70% moisture content. The test results showed that an acceptable pellet quality was not achieved, in spite of the fact that green ball properties were at an acceptable level.

3. Additional balling tests were carried out on optimization of these two binders in a laboratory balling tire and 1 meter balling disc. Good green ball quality was achieved with 0.09% Alchem addition as received, sprayed directly on the balling disc, thus bypassing the mixing operation in a blender and the P-Kay mixer.
   Because of the presence of coke breeze in the filtercake, peat moss addition was lowered to 0.5% (dry) and 0.1% NaOH. Pot grate test results showed that further optimization is necessary for acid pellet production to meet the pellet quality specification.
   Filtercake without coke breeze is required in order to balance internal heat when using organic binders.

4. The pot grate results on fluxed pellets using Alchem 8C26 and peat moss as a binder showed good results. With 0.09% Alchem 8C26 addition, tumble index of 4.7 and fired compression of 255 kg/p were obtained. The physical quality obtained is slightly lower than with bentonite. On the other hand very good results

were achieved for metallurgical properties: reducibility 1.33, porosity 33.2, swelling 11.8, LTD 96.7. It should be noted that the green ball moisture for these tests was at 8.5% level. Lower physical quality was produced with 0.5% peat and 0.1% NaOH addition for fluxed pellets. Green ball moisture was 8.6%, which is lower than the current operating level. Tumble of 4.6 and fired compressions of 202 kg/p were produced. This is a result of excessive internal heat (peat plus coke breeze). In spite of the lower physical quality, good metallurgical properties were achieved - reducibility 1.36, porosity 30.7, swelling 13.5 and LTD 95.4. It is believed that lower internal heat (peat and coke breeze) could result in better physical quality.

5. Based on the test results for fluxed pellets, there is a good indication that peat moss could be used as a potential binder and partial or complete replacement for coke breeze.

6. With respect to economical aspect of the two potential binders tested, further testwork on optimization is required particularly for acid pellet production to redefine if desired pellet quality can be produced.

7. It is recommended to carry out further testwork with Alchem and peat moss as potential binders. This testwork should include the laboratory tire balling and full scale pot grate tests. Use of these potential binders combined with bentonite, limestone and dolomite should be tested to find an adequate pelletizing mix which will produce a good physical and metallurgical quality. Details of the proposed testwork will be outlined in Phase IV of the program.

7.0 APPENDICES

APPENDIX I

CRM REPORT OF 1986-02-17

Ministère de l'Energie et des Ressources
CENTRE DE RECHERCHES MINERALES
Complexe Scientifique
2700, rue Einstein
Ste-Foy, Québec
G1P 3W8

IRON ORE COMPANY OF CANADA

Project 2409

BENTONITE SUBSTITUTION IN IRON ORE PELLETIZING

Final report
February 17th, 1986

COPIE NO: 2

Gouvernement du Québec
Ministère de l'Énergie et des Ressources
Centre de Recherches minérales

Sainte-Foy, February 26th 1986.

Mr. Tom I Martinovic
Pellet Plant
P.O. Box 1000
Labrador City (Newfoundland)
A2V 2L8

Dear Sir,

Please find enclosed herewith a copy of Mr. G. Paquet's report on the laboratory evaluation of different binders for bentonite substitution in the iron ore pelletizing process.

Among the nine (9) different binders investigated, four (4) have shown a good potential for bentonite substitution. Following our recommendation to further evalutate peat moss and Alchem 8-C-26 binders at the pilot scale, you requested CRM to proceed with and the testing is actually under way at our pilot plant.

We hope that our studies meet with your approval and I assure you that the Centre de Recherches Minérales is pleased to collaborating with IOC towards a successful completion of the project.

Sincerely,

Alain Claveau, Eng.
Director of Mineral
Processing Research

AC/11

Complexe scientifique, 2700 rue Einstein, Sainte-Foy, Québec G1P 3W8

Report to the attention of :

Mr. George Chung
Manager, Pelletizing
Iron Ore Company of Canada
Pellet Plant
P.O. Box 1000
A2V 2L8

Prepared by :

Mr. Guy Paquet, Ing.
Project engineer
Pilot Plant

Signature : Guy Paquet

Approved by :

Mr. Gontran Foy
Head of Pilot Plant

Signature : Gontran Foy

Date : February 17th, 1986

SUMMARY

Among the products investigated, four have shown a good potential for bentonite substitution and it is recommended to further evaluate them on a one meter diameter balling disk and in a pot grate simulator.

The first binder is Alchem 8-C-26. Good results were obtained at a 0,125% addition rate and a fairly high feed moisture level (9,5%). Dry green ball surface quality was questionnable.

The second product is peat moss. Good balling was achieved at a 1,0% dry basis addition, 0,20% NaOH and above 10% moisture in the feed. Peat moss may also have the advantage of increasing fired pellet porosity and reducibility.

The other two binders are Peridur and Hercules 6-CTL. These are very similar products in their aspect and binding properties. A 0,2% addition rate gave very good green ball properties but again the dry ball surface quality was questionnable.

The other products tested could not meet the company specifications on green ball quality.

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1. INTRODUCTION

The iron ore pelletizing process has been developed for the purpose of supplying a better feed to the blast furnaces. Since the beginning of the process bentonite was the only efficient binder used by the pellet producers. Besides its good binding properties, bentonite has a high water retention capacity which helps in the controlling of the agglomeration process.

However, bentonite contaminates the fired pellets by increasing the amount of silica and alumina at the expense of the iron content. This translates into higher transportation costs. It may also affect the blast furnace productivity and energy consumption. In addition, good quality bentonites are becoming scarce and expensive.

For these reasons, over the last few years pellet producers have shown an increased interest in the search for a substitute to the bentonite.

Representatives from Iron Ore Company of Canada have recently commissioned the Centre de Recherches Minérales du Quebec to investigate the efficiency of various binders in a small laboratory balling tire. The objective was to determine if one or several of these products could be considered as potential substitutes for bentonite.

2. CONCLUSIONS

Among the various binders investigated, four have shown a good potential for the substitution of bentonite.

The first one, Alchem 8-C-26, is of unknown chemical composition but has good performance at very low addition rate and would probably have the advantage of not increasing the gangue. However, the dry green ball surface is easy to deteriorate and this may badly affect the fired pellet quality. Alchem 85030 gave similar results except for a lower green ball dry strength.

The second one is peat moss, an organic fibrous material. Good green ball quality was obtained at a 1,0% dry basis addition rate in presence of 0,2% NaOH. This product would volatilize in the pellet firing stage and may lead to increased pellet porosity and reducibility. Its heat content may also contribute to lower energy cost. The pellet would not be gangue contaminated as it does with bentonite.

The other two binders, Peridur and Hercules 6-CTL, are very similar in their aspect and binding properties. Peridur is a cellulose derived organic binder and would also volatilize in the firing stage. Hercules is of unknown chemical composition. At a 0,2% level, the green ball quality obtained with either one of these products was equivalent to a 0,8% bentonite addition. However the dry green ball surface was, as with Alchem 8-C-26, easy to deteriorate.

Procell, lignosol, burnt lime, quick lime and sodium silicate could not meet the company specifications on green ball quality.

3. RECOMMANDATIONS

It is recommended to further investigate the following binders in a one meter diameter balling disk and to measure their effect on fired pellet quality after firing the green balls in a pot grate:

- Alchem 8-C-26 at a 0,125 % addition rate.
- Peat moss at a 1,0% dry basis level with an addition of 0,20% sodium hydroxyde.
- Peridur at a 0,20% addition rate.

If none of these binders leads to satisfactory results, it is then suggested to look at other products (Carbinder: Union Carbide, sawdust, sea weed extract, Min-U-Gel CW: Floridin company, Reedi-Gel: Oglivy Mills Industrial Grain Products, etc.).

4. EXPERIMENTAL PROCEDURES

All the tests were done in a laboratory balling tire as illustrated on figure 1. The test procedure is detailed in appendix.

The filter cake analysed 69,4% -325 mesh. This concentrate was taken out of the shipment we have received in April 1985. The products investigated were: Bentonite (reference test), Alchem 8-C-26, Alchem 85030, Procell, peat moss, Peridur, Lignosol, burnt lime, quick lime, sodium silicate an Hercules 6-CTL. These products were used as received except for Procell and peat moss which, in some tests, were reground in a Raymond mill.

Figure 1 : Photograph of the balling tire

5. RESULTS AND DISCUSSION

5.1 Bentonite

Table I summarizes the results obtained in the reference tests with 0,8% Wyoming bentonite and without any binder. The green ball properties obtained with bentonite are typical of good balling performance. The test with no binder was characterized by a low water retention capacity and little control on pellet growth kinetics.

5.2 Alchem 8-C-26 and 85030

These products were supplied by Alchem Inc. Burlington, Ontario. They are pale yellow solutions of unknown chemical compositions. Table II shows the green ball properties obtained at different addition rates of these products.

The first test was done at a 4,0% addition rate as suggested by Alchem Inc. This rate appeared to be too high as the balls were sticky, very plastic and easy to deform.

At rates lower than 0,2%, better results were observed as shown in table II. The drop number and the dry compressive strength Vs the amount of 8-C-26 added are reported on figure 2. Dry compression increases with the amount of binder added but the drop number seems to reach a maximum around 0,1% 8-C-26. It decreases beyond this level. A rate of 0,125% represents a good compromise and is recommended for a pilot scale test.

The Alchem 85030 gave similar wet properties but the green ball dry strength was lower.

Table I

Green ball properties with and without bentonite addition

% Bentonite	H_2O in G.B. (%)	Drops	Wet comp. (kg)	Dry Comp. (kg)	-16 + 9,5 mm (%)
0	7,2	1	1,2	0,4	93
0,8	8,4	11	1,7	6,0	95

200

Table II

Evaluation of the Alchem products

Type of binder	Rate (%)	H_2O in G.B. (%)	Drops	Wet comp. (kg)	Dry Comp. (kg)	-16 + 9,5mm (%)
8-C-26	0,15	9,7	11	1,0	4,7	97
"	0,125	9,6	16	1,0	2,9	95
"	0,10	9,3	19	1,6	1,8	91
"	0,075	9,6	9	1,0	0,5	64
"	0,05	9,4	6	0,9	0,3	52
85030	0,125	9,4	19	1,5	2,0	92
"	0,10	9,9	18	1,6	0,7	96

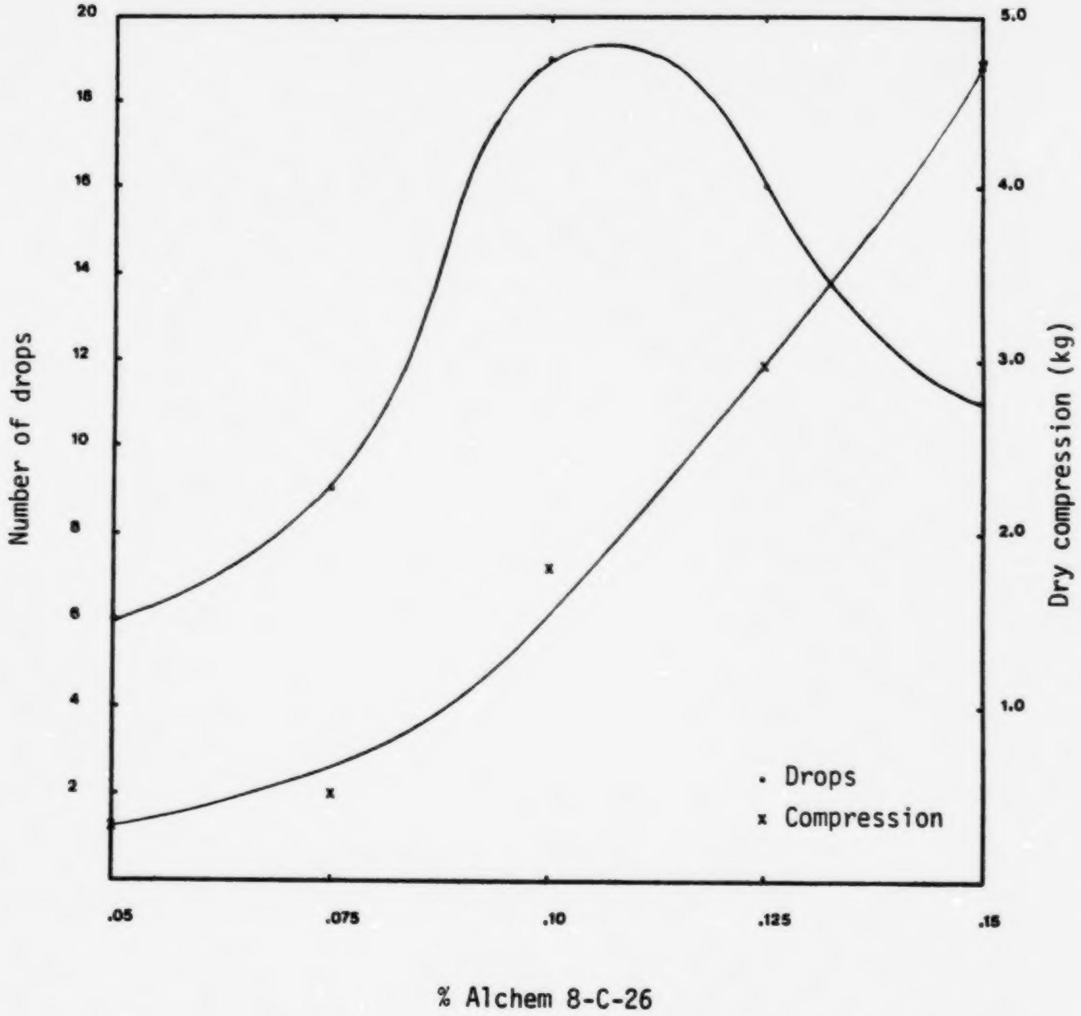

Figure 2 : Amount of binder Alchem 8-C-26 Vs the drops and dry compression of the green balls.

The balling behaviour with these products was different than that with bentonite. Ball growth rate was lower and very much dependent on water addition. Good balling was achieved with a moisture content around 9,5% which is about 1% higher than that with bentonite. This higher moisture may require a longer drying time in the induration machine. In addition, the green ball surface was glossy and handling of the dry balls generated dust due to surface deterioration.

This moisture level and the deterioration of the dry balls could badly affect the fired pellet quality. It is strongly suggested to evaluate these effects in a pot grate.

Because of the low addition rate required this binder will not contaminate the pellet as does bentonite. If good fired pellet quality can be obtained and if the cost of this product is reasonable, Alchem 8-C-26 may become an excellent substitute for bentonite.

5.3 Peat moss

Peat moss is an organic fibrous material with a good water absorption capacity. The test material's moisture content was about 70%. This fairly cheap product would have the advantage of being burnt off during induration, thus leaving the pellet chemistry unchanged while possibly increasing the porosity and reducibility of the fired pellets. In addition, its calorific value may contribute to the lowering of the fuel consumption.

The first series of tests was done with peat moss as received, that is to say 76,4% H_2O and 16% -200 mesh. This sample was undoudtedly dried at some stage since ground samples run anywhere from 85% to 96% moisture. From the results of the first 2 tests detailed in table III, it can be seen that green ball dry strength is much better when NaOH is added to activate the peat.

Table III

Evaluation of peat moss

Binder	% H_2O Peat	% Peat dry basis	NaOH (%)	H_2O in GB (%)	Drops	Wet Comp. (kg)	Dry Comp. (kg)	-16+9,5 mm (%)
Peat as received	76,4	0,47	-	9,5	3	0,9	0,3	85
"	"	0,47	0,10	9,6	3	1,1	2,9	97
"	"	0,71	0,10	10,7	4	0,8	2,9	95
"	"	1,00	0,10	11,9	7	0,9	2,8	98
Peat as received + 0,4 % lignosol	"	0,40	-	8,6	2	1,1	2,0	98
Ground peat (39% -200 M)	73,4	0,40	0,10	10,6	6	1,2	4,4	98
Ground peat (70% -200 M)	70,0	0,90	0,10	10,3	4	1,1	4,6	97
Ground peat* (70% -200 M)	"	1,00	-	10,4	5	1,0	0,2	99
" *	"	"	0,05	11,2	6	1,0	1,9	99
" *	"	"	0,20	10,7	11	1,2	4,8	99

* Tests done by R. Tremblay from CRM in 1983

The two next tests show that increasing the peat moss addition rate leads to an increased drop number. At a level of 1,0% peat moss (dry basis) the green ball quality was barely acceptable.

The next test was done with a combination of peat moss and lignosol without NaOH. Lignosol is known as a hardener and, in fact, the green ball dry compression was good. However the number of drops was very low.

The best results were obtained with ground peat moss, specially for the dry compressive strength. 40% -200 mesh seems to be an acceptable grinding level.

The 3 last tests clearly demonstrate the effect of NaOH addition on drop number and dry compression. At 1,0% peat and 0,2% NaOH a very good green ball quality was obtained. However, a high feed moisture content is necessary to achieve good balling and this may cause some drying problems in the induration machine.

It is recommended to further investigate peat moss at a pilot scale in order to determine its effect on fired pellet physical and metallurgical properties.

5.4 Procell

Like peat moss, Procell is an organic fibrous material. Its moisture content as received was 49%. This product, supplied by Stake Technology Ltd, is derived from steam processed aspen wood and was produced in Minnesota.

As shown in table IV the first 4 tests were done with the Procell as received at different rates, with and without NaOH addition. Green ball quality is not acceptable mainly because of the low drop number. The previous considerations with peat moss and NaOH regarding dry strength seem to apply also to Procell.

In the following tests Procell was ground and the rate increased with no major effect on green ball quality. Lignosol addition increased the dry compression as expected but the drop number was still too low. The mixing of Procell and bentonite on a 50%-50% basis did not lead to better results.

In the organic fibrous type of product we believe that peat moss deserves more attention for further investigation.

5.5 Peridur

Peridur is a cellulose derived organic binder. The cellulose molecule is a polysaccharide in which the repeating anhydroglucose units are B-1,4 linked. Peridur is obtained by a suitable substitution of some of the hydrogen atoms in the 3 hydroxyl groups, in each of the anhydroglucose units. Since it is an organic material it also has the advantage of being volatilized in the pellet firing stage. The Peridur we have used was in the form of a white powder.

Table V shows the very good results obtained with this binder at a low addition rate. An addition of 0,2% Peridur gave approximately the same green ball properties as the reference test with 0,8% bentonite.

Since Peridur and Lignosol are two wood by products and since they can be mixed by the same company before shipping it was decided to run a test with a combination of these products. The green ball quality was poor so that this avenue was abandonned.

Table IV

Evaluation of Procell

Binder	% H_2O Procell	% Procell dry basis	NaOH (%)	H_2O in GB (%)	Drops	Wet Comp. (kg)	Dry Comp. (kg)	-16+9,5 mm (%)
Procell as received	49	0,41	-	8,3	2	0,8	0,4	97
"	"	0,41	0,10	7,9	2	1,1	2,0	90
"	"	0,82	-	8,1	2	0,9	0,6	90
"	"	0,82	0,10	8,3	3	1,2	2,1	96
Ground Procell (23% - 200 mesh)	29	1,14	-	8,9	3	1,1	0,9	99
"	"	1,14	0,10	8,8	4	1,2	1,6	94
Ground Procell + 0,4% lignosol	"	1,14	-	8,2	4	1,2	2,9	90
Ground Procell + 0,4% bentonite	"	0,40	-	7,5	2	1,3	1,6	95

Table V

Evaluation of Peridur

Binder	Peridur (%)	H_2O in GB (%)	Drops	Wet comp. (kg)	Dry Comp. (kg)	-16+9,5mm (%)
Peridur	0,20	8,3	11	1,7	7,2	98
Peridur + 0,4% lignosol	0,10	7,4	3	1,2	3,9	96
Peridur + 0,4% bentonite	0,10	8,4	12	1,5	7,4	86

The last test was done with a Peridur-Bentonite mixture on a 50%-50% basis. Results were equivalent to 0,2% Peridur alone. As mentionned in section 5,2 with Alchem 8-C-26, the green ball surface obtained with Peridur was glossy when wet and easy to deteriorate when dry. Because of these characteristics, it is strongly recommended to evaluate Peridur's effect on fired pellet quality by running some pot grate tests.

5.6 Various binders

Table VI summarizes the results obtained with various other potential binders.

5.6.1 Lignosol BD

The product is, like peridur, a cellulose derived organic binder. It can be obtained as a yellow powder or as a thick dark syrup. For our test the yellow powder was used. As shown in table VI wet green ball quality was poor but the dry strength was very good. It is concluded that this product is a poor binder but a good hardener.

5.6.2 Burnt and quick lime

The results obtained with these products are indicative of very poor binders. We believe it is useless to do any further work with them.

5.6.3 Sodium silicate

The results obtained at a 0,2% addition are poor. Increasing the addition could lead to better green ball quality but the sodium content in the fired pellets would also increase. It is known that sodium has to be kept to a minimum because of its deleterious effect in the blast furnace. We therefore did not run any further tests with Na_2SIO_3.

Table VI

Results with various other binders

Binder	Rate (%)	H_2O in GB (%)	Drops	Wet comp. (kg)	Dry Comp. (kg)	-16+9,5mm (%)
Lignosol BD	0,8	7,0	2	1,0	5,1	99
Burnt lime	0,8	7,1	2	1,1	0,9	85
Quick lime	0,8	7,1	1	1,2	0,5	97
Na_2SiO_3	0,2	7,6	2	0,7	0,8	85
Hercules 6-CTL	0,2	7,9	9	1,5	8,7	85

5.6.4 Hercules 6-CTL

The aspect and binding properties of this product of unknown composition are similar to Peridur. If good fired pellet properties can be obtained with Peridur it will then be suggested to look at Hercules 6-CTL as an alternative.

Collaboration

The author appreciates the collaboration of Mr. Jean L. Blais, senior technician, and Mr. André Blais who have done the laboratory work, as well as the support of the clerical staff for the typing of this report.

Appendix

Balling procedure

Balling Procedure

1. Mix 2,4 kg of filter cake with the additives in a Hobart mixer for 2 minutes then screen on a 10 mesh.

2. Take 400 g and feed gradually in the tire while spraying water to form the seeds. Remove from the tire and screen on 1,65 mm.

3. Place 80 g of seeds (+ 1,65 mm) in the tire and gradually feed 700 g of material while spraying water. Remove from the tire after 2 minutes and screen on 1/4".

4. Place the + 1/4" back in the tire and gradually feed the rest of the material along with water to ensure good balling. Roll the balls in the tire for one minute in order to harden.

5. Screen on 5/8", 1/2", 3/8" and 1/4".

6. Measure the number of drops on 20 green balls. The drops are from a height of 18" on a steel plate.

7. Measure the wet and dry compressions on 20 balls. For dry compression, the balls are dried for 2 hrs at 105°C. Determine % H_2O.

APPENDIX II

CRM REPORT OF 1986-05-30

Ministére de l'Energie et des Ressources

Centre de Recherches minérales

Complexe Scientifique
2700, rue Einstein
Ste-Foy, Québec

Iron Ore Company of Canada

Project 2428
Phases I & II

Effect of some organic binders on fired pellet properties

Final report

May 30th, 1986

Gouvernement du Québec
Ministère de l'Énergie et des Ressources
Centre de Recherches minérales

Sainte-Foy, June 3, 1986.

Mr. Tom Martinovic
Energy Coordinator
Iron Ore Company of Canada
P.O. Box 1000
Labrador City (Newfoundland)
A2V 2L8

Dear Sir:

Please find enclosed herewith two (2) copies of Mr. Guy Paquet's report on the pilot scale evaluation of two organic binders for bentonite substitution in the iron ore pelletizing process.

Both, Alchem 8C26 and peat moss, showed good potential as substitute for bentonite but some optimisation has still to be made in order to improve the physical strength of fired acid pellets. On the other hand, excellent physical and metallurgical properties were obtained on fluxed pellets produced with both binders.

Considering the promising potential of these results, recommendation are made for further pilot scale investigation prior to the industrial implementation.

We hope that our studies meet with your approval and I assure you that the Centre de Recherche minérales is very please to collaborating with IOC towards a successful completion of this project.

Sincerely,

Alain Claveau, ing.,
Director of Mineral
Processing Research

AC/11

Complexe scientifique, 2700 rue Einstein, Sainte-Foy, Québec G1P 3W8

Report to the attention of:

Mr. Tom Martinovic
Energy coordinator
Iron Ore Compagny of Canada
Labrador City, NFLD.

Prepared by:

Mr Guy Paquet, Eng.
Project engineer
Pilot Plant

Signature:

Approved by:

Mr. Gontran Foy
Head of Pilot Plant

Signature Gontran Foy Ing.

Date: May 30th, 1986.

SUMMARY

This report presents the results and conclusions of a pilot scale study on the investigation of 2 organic binders in the iron ore pelletizing process.

The first binder is a liquid anionic polymer named Alchem 8C26 and the second is peat moss.

The performance of the organic binders during balling and firing are compared to bentonite. The impact on fired pellet quality is also discussed for acid and fluxed pellets.

Both binders showed good potential for the substitution of bentonite. Good results were specially obtained with fluxed pellets. In acid pellet production, it is shown that some optimisation has to be made in order to improve the physical strength of the pellet.

Recommendations are made for further research work with these organic binders.

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1. INTRODUCTION

In early 1986, the Centre de Recherches minérales du Québec (CRM), in collaboration with the Iron Ore Company of Canada and the Canadian Centre for Mineral and Energy Technology (CANMET), completed a study on the efficiency of various binders in a small laboratory balling tire. The objective then was to determine if one or several of the products could be considered as potential substitutes for bentonite.

The results indicated that 2 organic binders led to acceptable green ball quality. These products were peat moss and a liquid anionic polymer called Alchem 8C26. The recommendations were to further investigate the efficiency of these binders in a one (1) metre balling disk and to study their effects on fired pellet properties by firing the green balls in a pot grate (ref.: project # 2409).

A research program was elaborated following these recommendations. Since encouraging results were obtained from this preliminary work, the program was extended in order to optimize balling and firing conditions. Results from both phases are discussed in this report.

2. CONCLUSIONS

The results obtained with the organic binders Alchem 8C26 and peat moss showed a very good potential for bentonite substitution.

Good green ball quality was obtained with a low 0.09% rate of Alchem sprayed as received directly into the balling disk. This way of adding the binder ensured its good distribution in the filter cake and resulted in good balling behaviour. Mixing of the binder with the feed in a Pekay mixer prior to balling is not recommended because of poor binder distribution and sticking problems in the Pekay. The Alchem must be sprayed as received as a low viscosity solution can not be obtained at a reasonable dilution rate.

Green ball quality obtained at a 1.0% peat moss addition rate (on a dry basis) with 0.15% NaOH was acceptable. At a 0.5% peat rate and 0.1% NaOH, the drop number was low (3 to 4 drops).

The production of acid pellets with both organic binders led to poor physical properties. This is due, in our opinion, to the volatilization of the binder during firing, this results in increased pellet porosity and in poor bonding. In addition, peat moss (20 700 kJ/kg or 8900 BTU/lb) increases the heat content in the mix and the resulting high amount of energy released during firing contributed to lower pellet physical strength.

The addition of dolomite and limestone in the production of fluxed pellets resulted in much better physical properties. With 0.09% Alchem, a 4.7% tumble and a 256kg compression strength were obtained while with a 0.5% peat rate these results were respectively 4.6% and 202kg. We believe that the optimization of the firing conditions could lead to even better results. In addition, the metallurgical properties of the fluxed pellets were exceptionnally good with both binders.

Based on these very good results, we believe that research work should be continued to optimize the green ball and fired pellet qualities.

Improvement in acid pellet physical strength should be obtained by adding 1 or 2% fluxes. In testing with peat moss, different coke breeze addition rates should be tried in order to take maximum advantage of the peat heat content.

A combination of bentonite and either Alchem or peat moss could also result in optimum green ball and fired pellet quality.

Finally, the encouraging results obtained during this study leave us very optimistic about the future utilization of organic binders.

3. RECOMMENDATIONS

Considering the encouraging results obtained with both binders Alchem 8C26 and peat moss, the following recommendations are made for further research work:

- A study on the effect of 1 ou 2% flux addition on acid pellet physical properties with both organic binders.
- Testwork with peat moss and different coke breeze levels in the filter cake.
- Other tests with both binders and fluxed pellets to confirm the good results obtained and to optimize the fired pellet properties. A reference test with bentonite should be included in these tests.
- Tests with a combination of bentonite and either peat moss or Alchem should ensure good green ball quality and fired pellet strength while the organic binder should increase pellet porosity and reducibility. A combination of Alchem and peat moss with some flux addition may also be advantageous.
- It is also recommended to run some tests with Peridur which showed excellent balling results in project # 2409.

4. EXPERIMENTAL PROCEDURES: PHASE I

4.1 Strategy

In a first approach, phase I of the project consisted in 3 series of tests using the optimum binder addition rates determined in the balling tire tests (ref.: project # 2409). These rates were: 0.85% bentonite (reference test), 0.125% Alchem 8C26 mixed with the feed and, finally, 1.0% peat moss added on a dry basis with a 0.15% NaOH addition.

4.2 Description of raw materials and mixes

The filter cake and bentonite used were taken out of the shipment that IOCC sent us in April 1985. Table I shows the chemical analysis of these materials.

Table II gives a description of the 3 balling mixes used in this first phase. In order to calculate the heat content in the mixes, we assumed a value of 33,000 kJ/kg of carbon (14,180 BTU/lb); this is approximately equivalent to 250,000 BTU/t per percent coke breeze added in the feed (assuming 80%C in feed) The energy provided by magnetite oxidation has been calculated at 517.95 kJ/kg (see appendix 1).

Since the magnetite content in mixes B-2 and B-3 was lower than in mix B-1, we added 0.1% coke (0.08% c) to compensate. It should be noted that the heat content of peat moss in not accounted for in table II.

The technical and safety data for the Alchem 8C26 used in mix B-2 is given in appendix 2. This binder is an opaque, greyish white liquid anioic polymer of high viscosity.

The peat moss added in mix B-3 was ground at 27% -200 mesh in a hammer mill. Its moisture content after grinding was 75% meaning that 4% wet peat was added in order to obtain a

TABLE 1

Chemical analysis of the raw materials: Phase I

	Concentrate (%)	Bentonite (%)
Carbon	0.56	-
Fe	65.70	2.46
SiO_2	4.58	58.27
Al_2O_3	0.15	15.73
MgO	0.51	2.41
CaO	0.48	2.19
Na_2O	0.13	2.69
K_2O	<0.01	0.62
TiO_2	0.04	0.18
MnO	0.16	0.03
P_2O_5	0.03	0.06

TABLE II

Description of mixes: Phase I

Test #	Additives	% -325 M in feed	%Fe_3O_4 in feed	% C in Feed	% C added	% C Total	Total kJ/t Mag + Coke (BTU/t)
B-1 (P-1)	0.85% Bent.	68.9	46.4	0.56	-	0.56	425 130 (402,940)
B-2 (P-2A to C)	0.125% Alchem 8C26	69.7	38.0	0.56	0.08	0.64	408 020 (386,730)
B-3 (P-3A to D)	1.0% Peat 0.15% NaOH	69.5	37.1	0.56	0.08	0.64	403 360 (382,310)

rate of 1% on a dry basis. The peat moss was supplied by Mr. Dave Miller from Sept-Iles. Analysis of the heat content of the peat gave 20 700 kJ/kg (8,900 BTU).

4.3 Balling

The filter cake was conditioned in a Pekay mixer. The additives were added on a dry basis and mixed with the concentrate in a Sturtevant mixer for 2 minutes except for B-2 where the mixing time had to be shortened to 45 seconds because of early seed formation.

The mix was then pelletized in our one (1) metre balling disk (see figure 1). A Sweco screen was installed at the disk discharge and only the balls in the size fraction +9.5 -16.0mm were used for firing. For each test, the green ball properties such as %H_2O, drops, wet and dry compression strength were measured.

4.4 Firing

All the firing tests were done in our pot grate (shown in figure 2). Figure 3 shows the 38 cm diameter pot into which about 75 kg of green balls can be loaded. This pot has a waved refractory lining to minimize the side wall effect. A 10 cm fired pellet layer was used to protect the grate. In each test, 30 cm of green balls were loaded except for test P-3D in which a 34 cm bed was used.

Thermocouples located every 10cm in the bed measured the temperature in the hearth layer and in the bottom, center and top of the green ball bed. Aspirating thermocouples were used to measure the inlet and oulet gas temperatures. The pressure drop across the bed was also measured and recorded with all the temperatures on a process reporter.

The pot was not moved during operation. Dampers were used to switch from up draft to down draft flow. Oxygen was

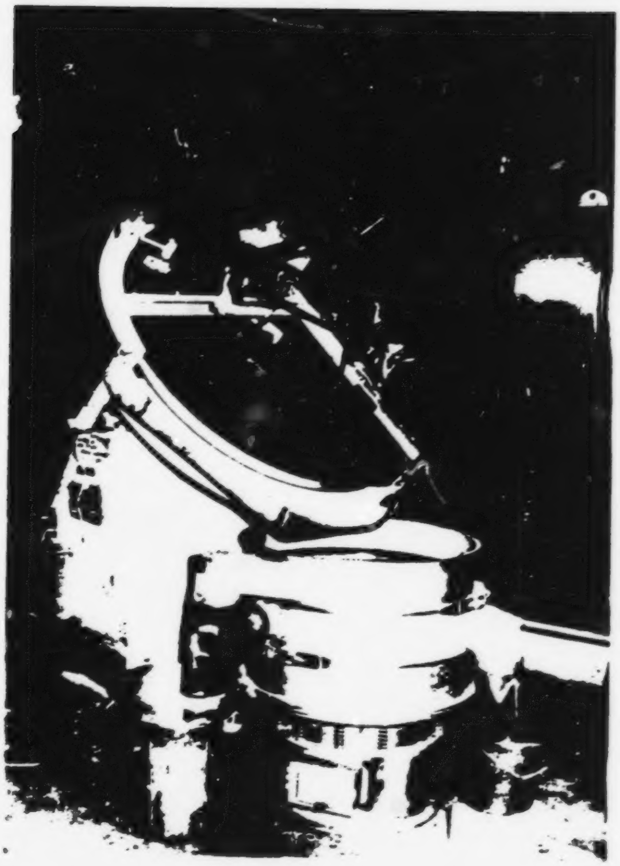
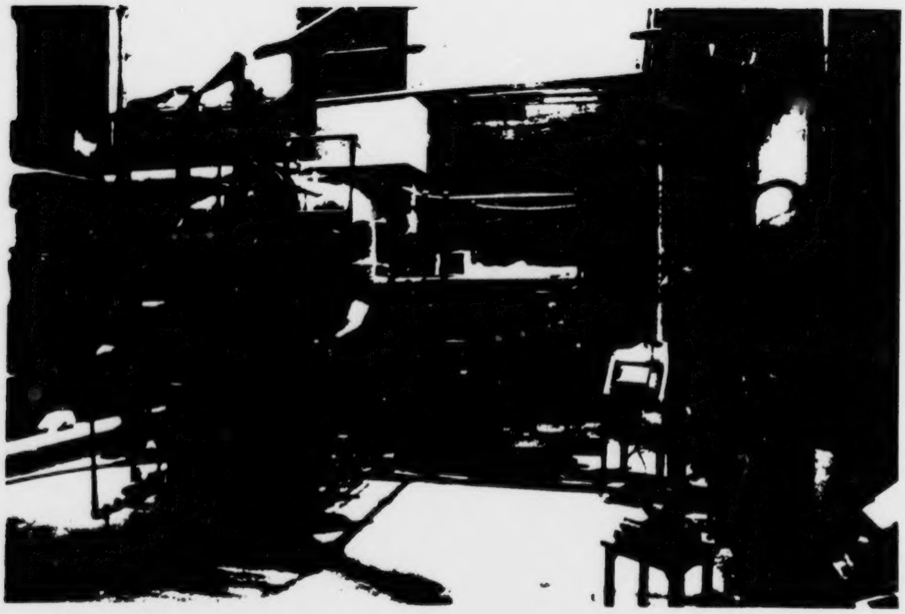


Figure 1: Photograph of the one metre balling disk.



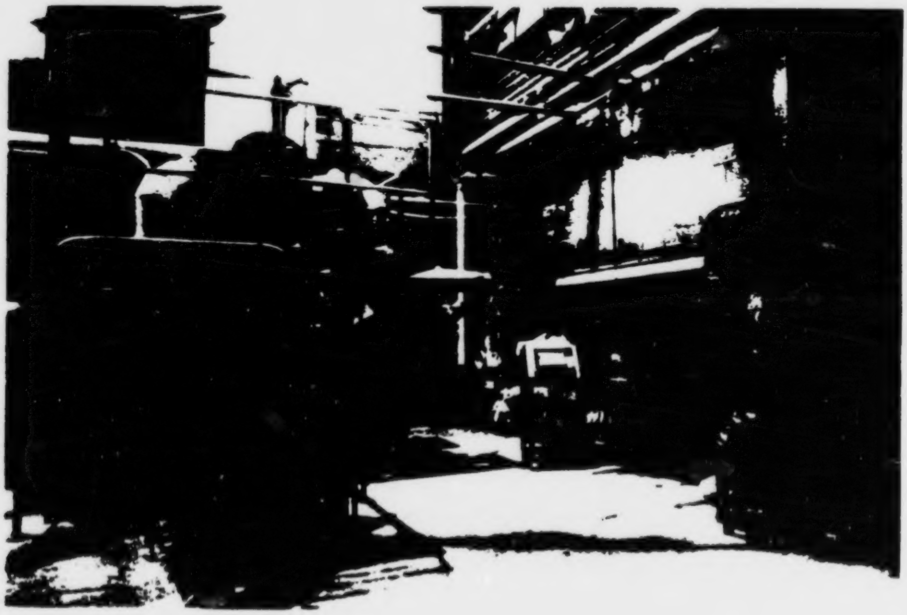


Figure 2: Photographs of the firing simulator (pot grate).

Figure 3: Photographs of the pot.

added in the inlet gas in the pre-heat and firing zones at respectively 300 and 600 l/min to ensure an oxydizing atmosphere for the whole duration of the tests. The time, pressure drop and temperature were closely controlled in each induration step.

At the end of the test, the pellets are unloaded with a vacuum cleaner. The top of the bed (15cm)is kept separately from the bottom (15cm) for further fired pellet quality determinations. The 10cm hearth layer is left in the pot for the next test.

The pellets located near the side wall are unloaded separately and rejected because this material is submitted to a poor heat transfer. In industrial terms these pellets correspond to the machine side wall. Since our pot has a diameter of only 38cm, this poor material represents about 25% of our production. In a large machine, the amount of side wall material is negligeable. The large amount of side wall material would bias the fired pellet properties. The practice of rejecting the side wall pellets is common to most laboratories.

4.5 Mesurement of fired pellet properties

Fired pellet samples from each series of tests were sent to our chemical laboratory for a full analysis.

Tumble indices were done according to the ASTM method. The compressive strength was measured using the ISO procedure on 30 pellets of each bed layer (top and bottom) for a total of 60 pellets.

The pellet porosity was determined according to the method using mercury immersion and an air pycnometer. Only the percentage of open pores was measured.

The metallurgical properties such as reducibility, swelling and Low Temperature Disintegration (LTD) were measured using the apparatus illustrated in figure 4. The ISO procedures were used for each of these tests. In the LTD test, 2% hydrogen was added.

The magnetic fraction in the fired pellets was measured with a Saturation Magnetic Analyser (Satmagan).

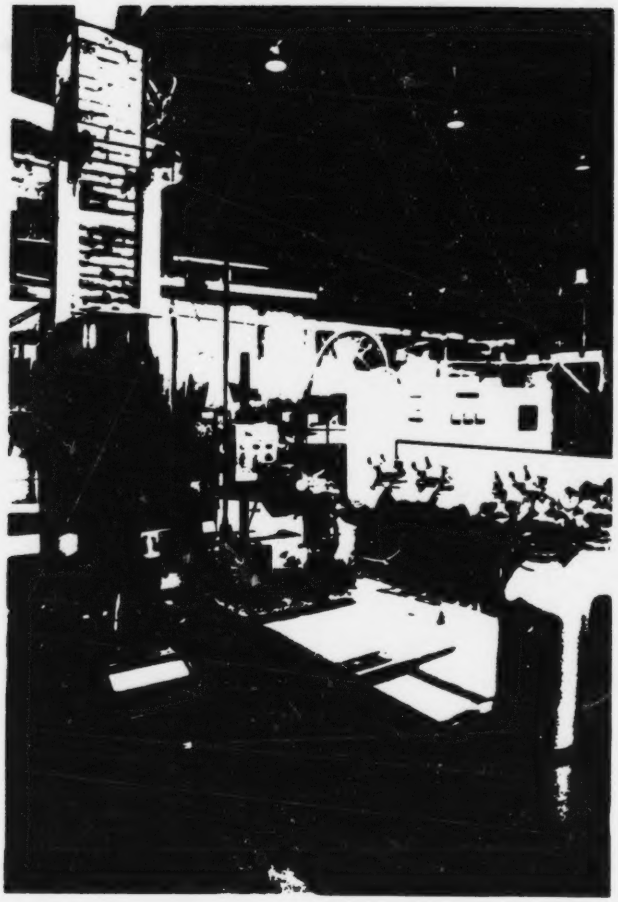


Figure 4: Photograph of the apparatus for measuring pellet metallurgical properties.

5. RESULTS AND DISCUSSION: PHASE I

5.1 Balling

For each test a sample was taken during the loading of the pot and green ball properties were determined; table III gives a summary of the results. Compared to bentonite, the Alchem 8C26 calls for more water in order to promote balling but the percentage of moisture in the balls is still acceptable. The dry compressive strength was lower and the dried ball surface was more sensitive to disintegration; this was also observed in the balling tire tests (ref. project 2409). The balling process was complicated by the fact that the binder was poorly mixed with the feed. Due to the very low rate of Alchem required, its distribution in the feed is very important. However, the residence time in the mixer had to be lowered from the usual 2 minutes to 45 seconds due to partial agglomeration of the material. The poor homogeneity of the mix led to irregular shaped green balls.

There were also sticking problems observed in the Pekay mixer, they were attributed to an excessive rate of binder.

The balling was also very sensitive to water addition in the disk. In order to improve the green ball plasticity the moisture had to be kept at a relatively high level. A small decrease in moisture led to a poor drop number while a slight excess caused soft and sticky green balls. Due to these problems, the balling rate was about 10% lower than with bentonite and the drop number was lower than tn the balling tire tests (ref. project # 2409).

Balling with peat moss was much easier and no major problems were noted. As expected, the water addition required to promote balling was very high due to the high water retention capacity of the peat. The green ball properties

TABLE III

Green ball properties: Phase I

Test #	Description	Moisture (%)	Nb. of drops	Wet compression (kg)	Dry compression (kg)
P-1	0.65% Bentonite	8.3	7	1.8	8.8
P-2A	0.125% Alchem 6C26	9.2	7	1.1	3.3
P-2B		9.1	7	1.0	3.1
P-2C		9.0	6	1.6	2.4
Average		9.1	7	1.2	2.9
P-3A	1.0% Peat on a dry basis +0.15% NaOH	11.2	6	1.2	3.3
P-3B		11.2	7	1.2	4.1
P-3C		11.1	6	1.3	4.6
P-3D		10.6	10	1.2	4.8
Average		11.0	7	1.2	4.2

obtained were similar to those in the balling tire tests and the balling rate was satisfactory.

5.2 Firing

The first test P-1 with bentonite was done with the following reference cycle:

Zone	Time	Cum. Time	T° (F)	ΔP (mm H_2O)
UDD	5'29"	5'29"	500	450
DDD	2'44"	8'13"	500	450
PH	1'58"	10'11"	1400	450
F-1A	1'34"	11'45"	1950	450
F-1B	3'08"	14'53"	2300	450
F-2A				
F-2B	1'34"	16'27"	2150	450
F-3	3'08"	19'35"	1900	450
F-4	3'55"	23'30"	1700	450
Cooling	12'30"	36'00"	amb.	500

P-2A and P-2B were also done using the reference cycle. P-2C was done with a 10% longer cycle (39.5 min. with a time distribution equivalent to the reference cycle) and a 50mm H_2O decrease in ΔP. P-3A used the reference cycle; P-3B had a 10% shorter cycle and P-3C was the same as P-3B but with a 50mm H_2O decrease in ΔP. P-3D was the same as P-3C but with a 34cm green ball bed instead of the usual 30cm.

Table IV gives the air flow rates measured for each test in standard l/min (21°C, 1 atm.). The firing temperature curves, along with the pressure drop across the bed, will be found in appendix 3. The original full size charts are being sent to IOCC with this report.

TABLE IV

Air flow rates (l/min.): Phase I

Test #	UDD	DDD	P.H.	F-1A	F-1B	F-2A	F-2B	F-3A	F-3B	A.F.	Cooling
P-1	11640	7560	6880	6060	4840	-->	4430	4300	-->	4430	12450
P-2A	11330	7920	6060	4840	4050	-->	3950	3670	-->	3900	12050
P-2B	11130	7740	6060	4840	4050	-->	3950	3670	-->	3670	11130
P-2C	9930	7740	6060	4840	4050	-->	3670	3510	-->	3670	9630
P-3A	12200	8280	7390	6060	4300	-->	4080	4000	-->	4150	12840
P-3B	12840	7920	7740	5810	4430	-->	4300	4430	-->	4840	14390
P-3C	12960	8100	7390	6340	4840	-->	4150	4150	-->	4300	12960
P-3D	11840	7920	7920	6060	4430	-->	4150	3950	-->	4000	11640

* 300 and 600 l/min. of oxygen were respectively added in the pre-heat and firing zones in all tests.

* P-3D had a 34cm green ball bed.

The following comments on firing can be made:

Test #	Description	Comments
P-1	0.85% bentonite ref. cycle	Normal behaviour, cycle well adapted. Firing T° curves normal.
P-2A	0.125% Alchem ref. cycle	Bed permeability slightly lower than P-1 (see flow rates table IV). Ball density about 5% lower. T° curves OK.
P-2B	same as P-2A	Same as P-2A. Good reproducibility.
P-2C	39.5 min cycle ΔP↓ by 50mm H_2O	Lower air flows due to lower ΔP. Bed and outlet gas T° higher due to longer cycle.
P-3A	1.0% peat and 0.15% NaOH ref. cycle	Permeability better than P-1. Ball density 10 to 15% lower. Energy consumption lower and pellets overfired due to extra internal heat coming from peat combustion. % O_2 in outlet gas lower because of peat combustion
P-3B	32.4 min. cycle	Firing less severe but still overfired. Other P-3A comments apply here.
P-3C	32.4 min. cycle ΔP↓ by 50mm H_2O	Firing less severe than P-3B but still overfired. Other comments apply.
P-3D	Same as P-3C with a 34cm bed height	Bed height increased to put a load equivalent to P-1 (bentonite). Smoother firing but still a little overfired. Decreased permeability due to greater bed height.

No spalling was noticed in any of these tests. Despite the very high moisture level in test series # 3, the drying was sufficient. The higher bed permeability probably helped the drying process. No severe fired pellet sticking or fusion was noticed.

In tests with peat, it may be observed that the heat front travelled fast, this caused the interface T° to increase rapidly (see T° curves). This phenomena can be explained by a combination of 2 factors: better bed permeability and higher bed internal heat provided by the peat moss combustion. We calculated that the 1.0% peat addition on a dry basis was equivalent in heat content to about 0.8% coke. The combustion of peat resulted in another 210 000 kJ/t (200,000 BTU/t) in the bed. One should take advantage of this extra energy by lowering the coke level in the filter cake.

Because of the low ball density, the usual 30cm bed height and firing time resulted in a 15 to 20% productivity loss. However, it was shown in test P-3D that it is possible to compensate that loss by speeding up the cycle and by increasing the bed height.

5.3 Fired pellet properties

Table V gives the fired pellet chemical analysis for a selected test from each series # 1 to 3 (bentonite, Alchem and peat moss). It can be seen that with organic binders the iron and silica contents in the fired pellets stay at the same level as in the concentrate. This is a well known advantage of organic binders.

Tables VI, VII and VIII summarize the physical and metallurgical properties of the fired pellets produced in each test. Some of the results are missing because of the tight schedule we had and because they were of secondary importance in the interpretation of the tests.

TABLE V

Chemical analysis of fired pellets: Phase I

	P-1 (Bentonite)	P-2B (Alchem)	P-3D (Peat moss)
% Fe	65.30	65.70	65.80
SiO_2	4.98	4.60	4.56
Al_2O_3	0.28	N/A	0.05
MgO	0.49	0.32	0.34
CaO	0.56	0.56	0.56
Na_2O	0.16	0.13	<0.10
K_2O	0.02	<0.01	0.01
TiO_2	0.07	0.06	0.02
MnO	0.15	0.16	0.17
P_2O_5	<0.01	0.02	0.01
C	0.02	0.03	0.02

TABLE VI

Fired pellet physical properties: Phase I

Test #	ASTM Tumble (%)						Compressive strength (kg)								
	Top		Bottom		Average		Top				Bottom				Average
	+ 1/4"	-28 M	+ 1/4"	-28 M	+ 1/4"	-28 M	$\overline{X}$	σ	-140kg	-90kg	$\overline{X}$	σ	-140kg	-90kg	
P-1	96.0	3.8	96.6	3.3	96.3	3.6	294	69.7	3.3	0.0	346	60.6	0.0	0.0	320
P-2A	93.7	6.1	92.7	7.1	93.2	6.6	217	47.8	0.0	0.0	221	68.4	16.7	0.0	219
P-2B	93.5	6.3	92.6	7.3	93.1	6.8	228	66.3	6.7	3.3	244	56.8	3.3	0.0	236
P-2C	94.4	5.4	93.7	6.1	94.1	5.8	227	46.3	0.0	0.0	259	66.7	3.3	0.0	243
P-3A	91.1	8.8	92.3	7.6	91.7	8.2	159	37.2	16.7	6.7	187	35.7	10.0	0.0	173
P-3B	90.3	9.6	92.8	7.1	91.6	8.4	148	30.9	26.7	10.0	175	32.0	16.7	0.0	162
P-3C	90.5	9.4	91.3	8.6	90.9	9.0	157	31.6	20.0	3.3	148	39.3	33.3	10.0	153
P-3D	91.2	8.7	92.8	7.0	92.0	7.9	155	35.1	33.3	0.0	190	39.9	13.3	3.3	173

TABLE VII

Fired pellet porosity and Satmagan: Phase I

Test #	Porosity (% open pores)			Satmagen (%)			FeO (%)	%Fe_3O_4 (FeO/0.31)
	Top	Bottom	Average	Top	Bottom	Average		
P-1	23.6	24.4	24.0	1.5	2.1	1.8	0.33	1.06
P-2A	-	-	-	0.8	0.8	0.8	-	-
P-2B	29.9	30.5	30.2	0.8	0.8	0.8	0.22	0.71
P-2C	28.7	29.2	29.0	0.9	0.8	0.9	-	-
P-3A	35.4	35.1	35.3	-	-	-	-	-
P-3B	35.5	35.2	35.4	-	-	-	-	-
P-3C	35.2	34.7	35.0	-	-	-	-	-
P-3D	35.3	34.5	34.9	2.5	1.3	1.9	0.07	0.23

TABLE VIII

Fired pellet metallurgical properties: Phase I

	ISO R_{40} (%O_2/min)			ISO Swelling		ISO LTD (%)			Softening
Test #	Top	Bottom	Avg.	ΔV	^{o}R	+ 6.3mm	+ 3.15mm	-0.5mm	T° (°C)
P-1	0.61	0.62	0.62	16.1	40.4	95.3	96.1	3.5	1190
P-2B	0.82	0.83	0.83	26.0	48.7	92.0	92.2	7.3	1162
P-2C	0.80	0.81	0.81	25.9	48.3	92.4	93.0	6.6	-
P-3D	0.60	0.59	0.60	22.6	43.4	93.5	93.6	6.0	1144

The reference test with bentonite showed the typical good fired pellet properties usually obtained in pot grate tests.

Test series # 2 with Alchem showed poor tumble indexes and a slightly low fired pellet compressive strength. These properties were improved by using a 10% longer cycle time in test P-2C (this would translate into a 10% lower machine productivity) but they were not improved enough to meet an acceptable level. The fired pellets were more porous and the pellet apparent density was consequently lower at 3.52 g/cm^3 compared to 3.77 in test P-1.

The higher pellet porosity obtained with the polymer Alchem can be tentatively explained by a lower green ball compaction. Since the binder forms a strong gel when in contact with water, particule movements and grain interlocking are restricted. This results in lower ball compaction and, consequently, in a higher fired pellet porosity.

This better porosity led to a better reducibility than in test P-1. However, the swelling index and LTD test results did not meet the specifications. The level of magnetite in the fired pellets was normal. The softening T^0 (based on ΔP = 100mm H_2O) was also lower than in test P-1. The mineralogical examination done by Mr. B. Kieller (see report in appendix 4) indicated that the pellets made from Alchem 8C26 were similar to those made from bentonite except for the higher porosity.

We believe that the main limiting factors in the improvement of the physical properties of the Alchem pellet were the poor green ball quality and pellet bonding due to the volatilization of the binder. In the longer P-2C cycle, the results obtained were probably the best we could expect.

The results of test series # 3 with peat moss also showed poor pellet physical properties. Despite the 4 different firing stategies used in tests P-3A to P-3D, no acceptable tumble index or compressive strength could be reached. This is due, in our opinion, to the high pellet porosity and also to bed overfiring caused by the combustion of peat. It can also be seen from table VI that, surprisingly, the top of the bed showed a better tumble index than the bottom. This can be explained by the fact that the high amount of internal heat in the bed causes the bottom of the bed to be exposed to a high temperature for a longer time than the top layer. The top cools down rapidly in the after firing zone while the bottom is getting the combined effects of internal combustion and heat transfered from the top.

The high porosity led to a low ball density of 3.21 g/cm^3 which is about 15% lower than that of pellets made from bentonite. Despite the very good porosity, the reducibility was low due to overfiring.

The swelling and LTD test results were better than those of the Alchem pellet but still off the specifications. The level of magnetite in fired pellets was good. The softening T^0 was 46°C lower than that of the bentonite pellet. We believe that this is due in major part to the higher porosity.

The mineralogical examination confirmed the high porosity and the severe pellet firing. The texture indicated strong slag bonding and hematite recrystallization.

From these results, it can be concluded that a rate of 1.0% peat moss on a dry basis is excessive. In our opinion, it is not possible to produce pellets with an acceptable tumble index and compressive strength at this peat moss addition rate and with the present test conditions. Lower carbon in the feed and flux addition would probably contribute, to some extent, to improve the fired pellet physical properties.

6. EXPERIMENTAL PROCEDURES: PHASE II

6.1 Strategy

Based on the encouraging results obtained in the preliminary phase, a second phase was initiated to optimize the balling and firing conditions in order to improve the fired pellet quality. This phase consisted in 4 series of tests (B-4 to B-7); B-4 was done with a 0.09% addition rate of Alchem 8C26. The main difference with B-2 being that, this time, the binder was sprayed in the disk itself in order to ensure a better distribution in the feed. B-5 was done with an addition of 0.5% peat moss on a dry basis and 0.1% NaOH since the results obtained in B-3 indicated that 1.0% peat was too much. B-6 and B-7 were respectively the same as B-4 and B-5 except that dolomite and limestone were added to produce fluxed pellets.

6.2 Description of raw materials

For this phase, fresh filter cake was used (March 1986 shipment). For B-6 and B-7 we used the ground dolomite and limestone we already had on hand. The chemical analyses of the raw materials are shown in table IX.

The filter cake analysed at 36.8% Fe_3O_4 and 66.5% -325 mesh. The heat content from carbon and magnetite in each mix has been calculated at 474,410 kJ/t (449,650 BTU/t), this is about 15% more than the phase I feed. With this heat content, coke breeze addition was not required. Again, the energy content does not account for peat moss which, at a 0.5% addition rate, provides an extra 105 000 kJ/t (100,000 BTU /t).

The peat moss added in mixes B-5 and B-7 was ground at 50% -200 mesh in a hammer mill. Its moisture content after grinding was 70%, this means that 1.67% of wet peat was added to obtain 0.5% on a dry basis. The peat moss in phase II

TABLE IX

Chemical analysis of the raw materials: Phase II

	Concentrate (%)	Dolomite (%)	Limestone (%)
Carbon	0.86	-	-
Fe	64.80	0.83	-
SiO_2	4.82	1.42	2.00
Al_2O_3	0.08	0.28	0.59
MgO	0.53	20.09	0.50
CaO	0.55	30.19	53.00
Na_2O	< 0.10	< 0.10	N/A
K_2O	0.02	0.02	N/A
TiO_2	0.04	0.01	-
MnO	0.23	0.05	N/A
P_2O_5	0.01	0.01	N/A

came from the same shipment as the one used for phase I.

6.3 Balling

The balling procedure and equipment are described in section 4.3. In tests B-4 and B-5, the polymer Alchem was sprayed in the disk itself as shown in figure 5. The viscous binder was pumped into an air stream and atomized. A venturi ensured a high air velocity for good atomization and also helped in pumping the binder. A positive displacement pump was used to ensure a regular rate of binder. The bottle of Alchem was held by a laboratory support sitting on a scale. With this system, the addition rate of Alchem could be regularly verified simply by measuring the weight loss per minute.

This special system was designed after several other trials (different pumps, nozzles, high pressure systems etc.) Two major problems had to be faced. First, we needed a good atomization of the binder. Since a low viscosity solution could only be obtained at less than 1% Alchem in water (above that the mix forms a gel) the water to be added in the feed would have been too high. We therefore had to feed the binder as received. Secondly, the very low addition rate (about 4 g/min) required a high precision controlling system.

The feeding system described above met all requirements.

The procedures for firing and for the determination of the fired pellet properties are described in sections 4.4 and 4.5.

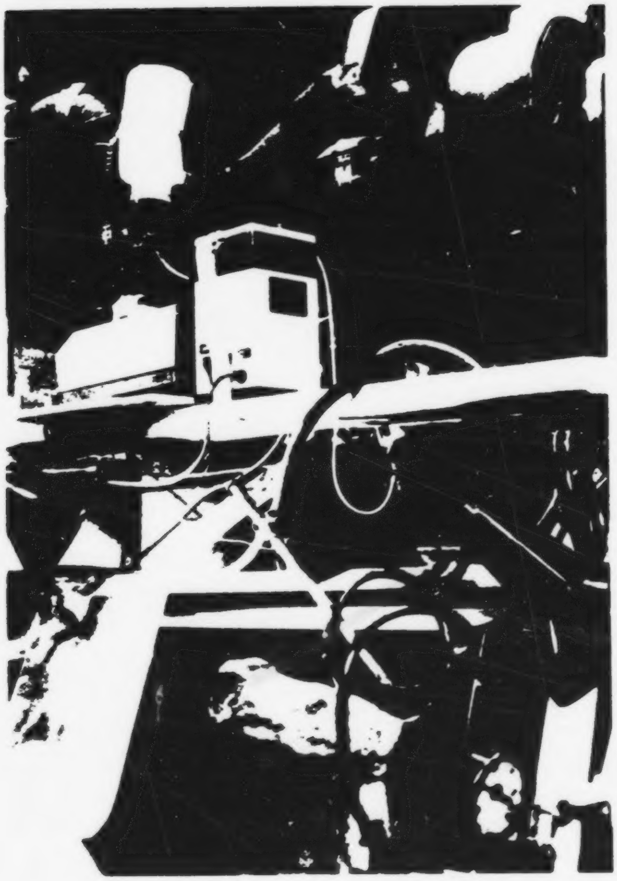


Figure 5: Photograph of the Alchem 8C26 feeding system.

7. RESULTS AND DISCUSSION: PHASE II

7.1 Balling tire tests

Before undertaking the pilot scale tests it was decided to run some laboratory balling tire tests. The results are summarized in table X. The test procedure is identical to the one described in the project # 2409 report.

The first 5 tests shown in the table were done with a 0.5% peat moss addition rate and with 0.1% NaOH. The peat was ground to different levels using a Raymond mill and a high speed hammer mill normally used for asbestos (Willow mill). Better results and balling behaviours were obtained with peat ground to about 40 to 50% -200 mesh. The type of grinding mill used did not make any significant difference. Since grinding was faster with the Willow mill, we decided to use it for the pilot tests. In all 5 tests, the drop number was very low due to the lower peat moss rate.

The next test done at a 0.3% peat rate and 0.1% NaOH resulted in a slightly lower green ball quality and a little more difficult balling. A safer peat rate of 0.5% was selected for pilot tests.

In order to improve the drop number, the next test was done with a mix of 0.3% peat and 0.1% Alchem. The green ball % H_2O and the drop number went up drastically as expected but the dry compressive strength decreased indicating that some NaOH should be added. No other mixes were tried because of the tight schedule but we believe that the mixing of 2 binders could be advantageous in optimizing balling as well as the physical and metallurgical properties of the fired pellets.

Some information from an Autralian mine indicated that they are adding a very low 0.01% polymer rate (a

TABLE X

Results of the laboratory balling tire tests

Binder	% H O in Peat	% Peat (dry basis)	NaOH (%)	pH of mix	Green ball properties			
					% H_2O	Drops	kg (wet)	kg (dry)
Peat as rec'd 11.3% -200 M	76	0.5	0.1	11.3	9.5	3	1.0	2.7
Ground peat Willow mill 35% -200 M	72	0.5	0.1	10.9	9.4	4	1.1	3.7
Ground peat Willow mill 45% -200 M	71	0.5	0.1	11.2	9.1	4	1.2	2.7
Ground peat Raymond mill 38% -200 M	69	0.5	0.1	11.5	9.0	3	1.2	4.0
Ground peat Raymond mill 50% -200 M	60	0.5	0.1	11.6	8.7	3	1.3	4.6
Ground peat Raymond mill 50% -200 M	60	0.3	0.1	10.9	8.6	3	1.0	2.8
Ground peat Willow mill 45% -200 M + 0.1% Alchem	71	0.3	-	8.7	10.8	10	0.9	0.8
0.01% Alchem (0.2% sol. sprayed) Feed dried at 4% H_2O	-	-	-	N/A	7.4	1	1.1	0.6
0.01% Alchem (0.2% sol. pre-mixed)	-	-	-	8.8	8.1	3	0.9	0.2

polymer called Almin PA) as a 0.2% solution with good results. The dry grinding process used in their plant allowed them to add the polymer in the make up water prior to balling. The addition of 0.01% polymer at this dilution level results in a 5% moisture increase in their feed which, consequently, has to be around 4% moisture before the binder is added.

The last 2 tests in table X were done following these indications. The filter cake was dried to 4% H_2O and a 0.2% Alchem solution was prepared; 5% of that solution (0.01% Alchem 8C26) was then added in 2 ways: pre-mixed with the concentrate and sprayed directly in the balling tire. Green ball properties were very poor in both tests and do not meet IOCC specifications for the actual pellet plant.

7.2 Balling disk results

Table XI summarizes the green ball properties obtained in test series # 4 to 7.

In test # 4, very good balling was achieved with our specially designed Alchem feed system. Green ball quality was much better than in test # 2 (phase I). Despite the lower polymer rate (0.09% compared to 0.125% in test # 2) the drop number was higher and the balling process healthier.

Test # 5 with peat also showed good balling. Green ball properties are similar to those obtained in balling tire tests with a sligthly better dry compressive strength. Balling was done at about 8.8 to 9.0% H_2O. The moisture levels measured in test P-5A, B and C are lower; this means that some drying occured. However, in our opinion, it did not affect the firing process significantly.

In test # 6, balling was more difficult. the presence of dolomite and limestone in large amounts affected balling and green ball quality. The moisture could not be

TABLE XI

Green ball properties: phase I

Test #	Description	Moisture (%)	Nb. of drops	Wet compression (kg)	Dry compression (kg)
P-4A	0.09% Alchem sprayed in the disk	9.4	8	1.6	3.2
P-4B		9.3	14	1.8	2.3
P-4C		9.5	13	1.8	2.6
P-4D		9.4	17	1.9	2.5
Average		9.4	13	1.8	2.7
P-5A	0.5% Peat on a dry basis +0.1% NaOH	8.5	4	1.8	4.5
P-5B		8.3	4	1.8	N/A
P-5C		8.0	4	1.7	5.4
Average		8.3	4	1.8	5.0
P-6A	0.09% Alchem with fluxes	8.5	7	1.5	1.8
P-6B		8.5	7	1.5	1.8
Average		8.5	7	1.5	1.8
P-7A	0.5% Peat 0.1% NaOH with fluxes	8.3	3	1.3	4.0
P-7B		8.5	2	1.4	4.4
P-7C		8.6	3	1.5	5.3
Average		8.5	3	1.4	4.6

increased beyond 8.5 because of sticking problems in the disk and, consequently, the drop number was lower than that in test # 4. However, the green balls produced were of acceptable quality.

Similar problems were observed in test # 7 with peat moss and fluxes.

The drop number obtained in tests # 5 and 7 with peat as a binder is lower than the specifications. If this number can not be increased, green ball transportation from the balling to the firing section may cause ball fractures and lead to poor fired pellet quality. This can only be verified during full scale testing.

7.3 Firing

In test series 4 with Alchem, the first 2 tests P-4A and 4B were done using the reference firing cycle described earlier in section 5.2. In P-4C, the pre-heating and firing T° were decreased as follows: PH = 1300°F, F-1A = 1850, F-1B + 2A = 2200, F-2B = 2100 and F-3 = 1850; the other T°, times and ΔP were kept the same. In test P-4D, the firing zone T° and times were modified as follows: F-1 = 1950 (3'08"), F-2 = 2150 (3'08"), F-3 = 2300 (3'55") and AF = 1800 (3'08"). The total cycle time and ΔP were the same.

Test P-5A with peat moss was done using the reference cycle. In P-5B, ΔP was decreased to 350mm H_2O and the firing profile modified as follows: PH = 1300, F-1A = 1850, F-1B = 2150, F-2 = 2300, F-3 = 1900 and AF = 1600; other conditions were kept the same. Test P-5C was also done at ΔP = 350mm H_2O using the following T° profile: PH = 1300, F-1A = 1900, F-1B = 2150, F-2 = 2300, F-3A = 2200, F-3B = 1900 and AF = 1600°F.

In tests P-6A and P-7A with flux pellets ΔP was increased to 500mm H_2O for the whole cycle and the firing T° used were as follows: PH = 1300°F, F-1A = 1900, F-1B + 2A =

2370, F-2B = 2250, F-3 = 2100 and AF = 1600. Other zone T° and total cycle time were kept the same. In tests P-6B and P-7B the only modifications compared to tests P-6A and 7A were: F-1B + 2A = 2330 and AF = 1700. Finally, the firing profile used for test P-7C was: PH = 1300°F, F-1A = 1900, F-1B + 2A + 2B = 2370, F-3 = 2100 and AF = 1600. Other conditions were the same as in P-7A.

Table XII gives the air flow rates measured for each test in standard l/min. The firing temperature curves and the pressure drop across the bed can be found in appendix 3. The original full size charts are sent to IOCC with this report.

The following general comments can be made on firing:

Test series # 4:	Bed permeability was better than in test series # 2 of phase I and, consequently, firing was easier. This is due to the much better green ball quality.
Test series # 5:	Compared to test series # 3 of phase I, the lower peat rate used here led to higher ball density and smoother firing. Bed permeability was good and % O_2 in the outlet gas was a little lower due to peat combustion.
Test series # 6:	Firing T° curves normal. Both cycles were well adapted and resulted in good firing. Permeability was good. Pellet density was lower than in test # 4 due to flux addition.
Test series # 7:	Unlike test series # 3 no overfiring was observed and pellet density was lower than in series # 5 due to flux addition.

No spalling or severe pellet sticking were observed in any of the tests.

TABLE XII

Air flow rates (l/min.): phase II

Test #	UDD	DDD	P.H.	F-1A	F-1B	F-2A	F-2B	F-3A	F-3B	A.F.	Cooling
P-4A	12840	7900	7340	6060	4740	-->	4280	4300	-->	4300	13780
P-4B	12150	7900	7720	6340	N/A	N/A	4150	4020	-->	4020	12990
P-4C	12150	8280	7900	6270	4640	-->	4150	4020	-->	4150	13170
P-4D	12250	7900	7560	6290	-->	4660	-->	4150	-->	4300	13170
P-5A	12250	8100	7740	6270	4660	-->	4430	4300	-->	4300	12960
P-5B	10930	7900	7560	6060	4230	3690	-->	3670	-->	3690	12760
P-5C	10930	8100	7560	6270	4840	4080	-->	3950	3900	3950	12150
P-6A	13270	7920	7560	6270	4460	-->	4860	4300	-->	4330	13630
P-6B	12960	7920	7560	6270	5600	-->	4840	4430	-->	4640	14190
P-7A	12960	7900	7560	6270	5250	-->	4740	4640	-->	4640	14190
P-7B	12760	7920	7560	6270	5580	-->	N/A	4430	-->	4640	13580
P-7C	13170	7920	7560	6800	5580	-->	-->	5040	-->	5040	13980

* 300 and 600 l/min. of oxygen were respectively added in the pre-heat and firing zones in all tests.

7.4 Fired pellet properties

Table XIII shows the fired pellet chemical analysis for a selected test from each test series # 4 to 7. The dolomite and limestone addition rates in test series # 5 and 6 were calculated based on a ratio $CaO/SiO_2 = 0.95 \pm 0.1$ and a MgO content of 1.7 ± 0.1 in the fired pellet. The procedure for calculation is shown in appendix 5. To meet the requirements 6% dolomite and 4% limestone were added in both tests.

The CaO and MgO contents in test P-6A are slightly lower than expected while the alumina content is a little high. We believe however that this had no significant impact on fired pellet properties. The iron content in flux pellets was around 62% as expected.

Tables XIV, XV and XVI summarize the physical and metallurgical properties of the fired pellets produced in each test.

Test series # 4 with Alchem 8C26 sprayed in the disk showed poor pellet tumble and compression. They were worst than those obtained in test series # 2 despite the better green ball quality. The lower binder rate (0.09% compared to 0.125%) could be an explanation. The pellet porosity and density were comparable to test series # 2. Tests P-4A and 4B done with the same firing cycle resulted in similar tumble indexes and are indicative of the good reproducibility obtained in pot grate tests. Test P-4C gave very poor pellet quality because of the cooler firing T°. The severe firing cycle used in test P-4D did not lead to better results than those of the reference cycle. This indicates that the pellet quality could not be improved by changing the firing profile only.

The lower 0.5% peat moss rate of test series # 5 led to improvements in pellet physical properties compared to those of test series # 3 (1.0% peat) mainly because of the

TABLE XIII

Chemical analysis of fired pellets: Phase II

	P-4B Alchem	P-5B Peat moss	P-6A Alchem + Fluxes	P-7A Peat + Fluxes
% Fe	65.20	65.20	62.50	61.90
SiO_2	4.96	4.96	4.92	4.94
Al_2O_3	0.25	0.18	0.59	0.23
MgO	0.46	0.51	1.44	1.71
CaO	0.50	0.48	3.62	4.08
Na_2O	<0.10	0.16	<0.10	<0.10
K_2O	<0.01	<0.01	<0.01	0.01
TiO_2	0.04	0.05	0.04	0.04
MnO	0.22	0.22	0.22	0.20
P_2O_5	<0.01	<0.01	0.01	0.01

TABLE XIV

Fired pellet physical properties: Phase II

Test #	ASTM Tumble (%)						Compressive strength (kg)								
	Top		Bottom		Average		Top				Bottom				Average
	+ 1/4"	-28 M	+ 1/4"	-28 M	+ 1/4"	-28 M	$\overline{X}$	σ	-140kg	-90kg	$\overline{X}$	σ	-140kg	-90kg	
P-4A	92.1	7.9	94.6	5.4	93.4	6.7	-	-	-	-	-	-	-	-	-
P-4B	92.4	7.6	94.4	5.6	93.4	6.6	177	37.5	20.0	3.3	207	51.8	10.0	3.3	192
P-4C	88.6	11.1	93.7	6.2	91.2	8.7	164	34.6	26.7	0.0	165	44.1	33.3	0.0	165
P-4D	91.9	7.9	94.6	5.3	93.3	6.6	165	37.6	26.6	0.0	203	36.2	3.3	0.0	184
P-5A	92.9	6.9	93.9	5.9	93.4	6.4	124	37.0	56.7	26.7	166	28.2	13.3	3.3	145
P-5B	94.5	5.2	94.4	5.4	94.5	5.3	165	35.9	23.3	0.0	214	44.4	6.7	0.0	190
P-5C	93.6	5.9	94.6	5.0	94.1	5.5	155	28.4	36.7	3.3	163	28.8	23.3	0.0	159
P-6A	95.0	5.0	95.5	4.4	95.3	4.7	252	46.9	0.0	0.0	259	62.4	3.3	0.0	256
P-6B	94.0	6.0	95.5	4.4	94.8	5.2	209	33.8	0.0	0.0	240	36.9	0.0	0.0	225
P-7A	95.0	4.8	95.4	4.3	95.2	4.6	194	39.3	6.7	0.0	210	39.3	3.3	0.0	202
P-7B	95.2	4.6	95.0	4.8	95.1	4.7	205	33.9	3.3	0.0	221	43.1	0.0	0.0	213
P-7C	95.6	4.2	95.6	4.2	95.6	4.2	194	36.8	3.3	0.0	188	28.2	3.3	0.0	191

TABLE XV
Fired pellet porosity and Satmagan: Phase II

Test #	Porosity (% open pores)			Satmagan (%)	FeO (%)	% Fe_3O_4 (FeO/0.31)
	Top	Bottom	Average			
P-4A	-	-	-	-	-	-
P-4B	29.7	29.7	29.7	3.8	1.04	3.35
P-4C	-	-	-	-	-	-
P-4D	30.1	29.8	30.0	3.1	-	-
P-5A	28.8	29.0	28.9	-	-	-
P-5B	29.1	29.1	29.1	10.5	2.16	6.97
P-5C	29.3	29.4	29.4	-	-	-
P-6A	33.2	33.2	33.2	6.9	0.42	1.35
P-6B	32.1	32.1	32.1	-	-	-
P-7A	30.7	30.7	30.7	10.5	1.25	4.03
P-7B	30.8	30.7	30.8	10.0	-	-
P-7C	30.4	30.3	30.4	10.4	-	-

TABLE XVI

Fired pellet metallurgical properties: Phase I

	ISO R_{40}	ISO Swelling		ISO LTD (%)			Softening
Test #	(%O_2/min.)	ΔV	°R	+ 6.3mm	+ 3.15mm	-0.5mm	T° (°C)
P-5B	0.66	22.2	43.0	95.1	95.7	4.0	-
P-6A	1.33	11.8	64.4	96.7	96.7	3.1	1221
P-7A	1.36	13.5	59.6	95.4	95.4	4.5	1224

lower pellet porosity. However, the tumble and compressive strength were still lower than the specifications. It should be noted that the fact of slowly increasing the T⁰ in the firing zone (tests 5B and 5C) resulted in better pellet properties. This can be explained by a smoother release of the internal energy (from coke, magnetite and peat). An improvement was also noticed in the LTD results probably because of the lower pellet porosity (6% lower than those in test series # 3). The high amount of magnetite measured in test P-5B may be due to secondary magnetite (formed during firing) which was not re-oxydized to hematite because of lack of time.

In test series # 6, the addition of fluxes resulted in very good pellet properties, specially in test P-6A where the firing T⁰ was higher. The average tumble index was very close to the specification and the compressive stength was well acceptable. These physical properties were obtained despite the relatively high porosity. The pellet density was low at 3.21 g/cm³ because of the high porosity and the large amount of fluxes added.

Based on plant results obtained with bentonite and fluxed pellets, it can be said that the metallurgical properties obtained in test P-6A with Alchem and fluxes are exceptionally good. The ideal would have been to run a pot grate test with bentonite and fluxes but it was not possible because of the tight schedule.

Very good results were also obtained in test series # 7 with peat moss and fluxes. No significant differences were observed between the results of tests P-7A, 7B or 7C despite the different firing T⁰ used. This is probably due to the extra energy provided by the combustion of peat which ensured good firing in all tests. The tumble index was slightly better than with Alchem. The pellet compressive strength was a little over 200kg, this is higher than the acid pellet produced in other tests with peat but slightly lower than the specifications. We believe this value is still acceptable considering that no pellets showed less than 90kg in compressive strength. Also, the very good metallurgical properties compensate for the lower strength. The porosity was slightly lower than with Alchem and the density a little higher at 3.28 g/cm³.

In summary, the production of fluxed pellets with both organic binders Alchem and peat moss lead to very encouraging results. Testwork should be continued to optimize green ball and fired pellet quality.

7.5 General comments

In acid pellet production, the volatilization of the organic binder results in a very porous pellet with poor bonding. This affects the physical strength of the pellets and leads to low abrasion and compression resistance. We believe that the physical properties obtained in test series # 4 and 5 (with acid pellet and organic binders) were about the best we could expect without flux addition. In some of these tests, severe firing profiles were used without any significant gain. On the other hand, it was shown in test series # 6 and 7 that flux addition was the solution in order to produce stronger pellets with organic binders. However, since the purpose of these tests was to produce fluxed pellets, a large amount of fluxes was added. We believe that the production of an acid pellet with acceptable abrasion resistance and compression is possible with organic binders by adding 1 or 2% dolomite or limestone.

We also suggest, in further tests with peat moss, the lowering of the carbon level in the mix to compensate for the heat content of the peat. It is known that a high release of internal energy during firing contributes to a lower pellet physical strength. In addition, the pellet production cost will be lowered by taking advantage of the heat content in peat moss.

It would also be interesting to do some testwork with a mix of 2 binders in order to obtain a good compromise between the green ball quality and the physical and metallurgical properties of the fired pellet. One advantage of the use of organic binders is the increase in pellet porosity and reducibility. On the other hand, bentonite leads to better pellet strength. A mix of bentonite and organic binder could result in a pellet of acceptable strength but with a better reducibility. The advantages of different binder combinations would be as follows:

Peat and bentonite:	- better green ball drop number and fired pellet strength than with peat alone; - better pellet porosity, reducibility and iron content; - lower coke breeze requirement due to heat content of peat.
Alchem and bentonite:	- better fired pellet strength than with Alchem alone; - better pellet porosity, reducibility and iron content.
Peat and Alchem:	- better green ball drop number than peat alone; - high pellet porosity, reducibility and iron content; - lower coke breeze requirement.

In the last mix, it is suggested to add 1 or 2 % fluxes to ensure good pellet strength.

COLLABORATION

The author appreciates the collaboration of Mr. Jean-Louis Blais, senior technician, and Mr. André Blais who have done the laboratory and pilot scale tests.

Appendix 1

Energy contribution from magnetite oxidation

Calculation of energy contribution from magnetite oxidation

Based on the following thermodynamic equation for the oxidation of magnetite to hematite:

$$2\ Fe_3O_4 + \tfrac{1}{2}O_2 \longrightarrow 3\ Fe_2O_3 + 57.289\ \text{kcal}$$

We can calculate the energy generated by the oxidation of 1 kg of magnetite as follows:

$$Fe_3O_4 = (3 \times 55.85) + (4 \times 16) = 231.55\text{g}$$

$$\frac{57.289\ \text{kcal}}{2(Fe_3O_4)} = \frac{57.289\ \text{kcal}}{463.1\text{g}} \times \frac{1000\text{g}}{\text{kg}} = 123.71\ \frac{\text{kcal}}{\text{kg}}$$

$$123.71\ \frac{\text{kcal}}{\text{kg}} \times 4.1868\ \frac{\text{kJ}}{\text{kcal}} = 517.95\ \frac{\text{kJ}}{\text{kg}}$$

$$\text{or} \quad 222.7\ \frac{\text{BTU}}{\text{lb}}$$

Appendix 2

Technical and safety data sheets for Alchem 8C26

ALCHEM® 8C26

MINERAL PROCESSING FLOCCULANT

- *ALCHEM 8C26 is a high-molecular-weight liquid flocculant designed for mineral processing settling and filtration operations*
- *Its single-component liquid form provides the following advantages over dry polymers*
  - *Dissolves immediately*
  - *Eliminates "fish-eyes" that occur with undissolved dry product*
  - *Permits safe and easy dust-free handling*
  - *Allows automation of make-up systems*
- *High activity provides maximum performance*

GENERAL DESCRIPTION

ALCHEM 8C26 is a high-performance, liquid anionic polymer. It is produced with specific functional groups to provide excellent settling, clarification, and dewatering of mineral processing slurries.

Form	liquid
Appearance	opaque, greyish white
Odour	hydrocarbon
Relative density at 25°C	1.08
Flash point	none
Freeze-thaw recovery	complete
Pour point	−5°C
*Viscosity at:	
0°C (No. 3 at 30 r/min)	15,000–16,000 mPa·s
25°C (No. 3 at 30 r/min)	900–1300 mPa·s
40°C (No. 3 at 30 r/min)	750–950 mPa·s
**Solubility	complete in water up to 1.5%
pH (1% concentration)	8.1
Charge in solution	moderately anionic

USES

ALCHEM 8C26 was developed to enable rapid solution preparation and to provide maximum activity in mineral processing operations where the pH of the water is greater than 6.0. Typical processes are:

- Clarification of recycle water
- Thickening and settling of refuse slimes
- Refuse slimes filtration
- Mineral concentrate thickening and filtration

DOSAGE

Dosage requirements vary depending upon overall effects desired and total percent solids in the slurry. Typical ranges for mineral applications are

Thin slurry thickening and clarification	0.5–10 mg/L
Heavy slurry filtration	0.005–5 kg/tonne of dry solids

FEEDING

A feed tank separate from the make-up tank is recommended to insure uninterrupted application. A centrifugal pump may be used to transfer solution of ALCHEM 8C26 from one tank to another. A positive displacement pump is strongly recommended for metering and feeding solutions of ALCHEM 8C26. Recirculation should be avoided.

The stock solution should be metered into a mixing tee and water line for continuous dilution to 0.1% or less upstream from the point of addition. Individual process applications may require greater dilution to optimize product performance. Feed the diluted ALCHEM 8C26 in a manner that provides maximum distribution to the slurry solids and minimizes shear. This is best accomplished with a distribution header. In addition multiple feed points can increase the polymer's effectiveness.

Carbon steel tank and pumps may be used for solution of ALCHEM 8C26. Galvanized metals and natural or synthetic rubbers should be avoided. Teflon or other inert materials should be used for gaskets and pump seals.

Cont'd.

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*Brookfield LVF

**Solubility is limited only by solution viscosity

ALCHEM INC.
BURLINGTON • ONTARIO

SPECIALIZED CHEMICALS AND ENGINEERING SERVICES

TO THE BEST OF OUR KNOWLEDGE THE INFORMATION CONTAINED HEREIN IS TRUE AND ACCURATE. NUMERICAL DATA UNDER "GENERAL DESCRIPTION" ARE NOT SPECIFICATIONS BUT ARE VALUES TYPICAL OF THE PRODUCT AS MANUFACTURED. ANY RECOMMENDATIONS OR SUGGESTIONS ARE MADE WITHOUT WARRANTY OR GUARANTEE. SINCE THE CONDITIONS OF USE ARE BEYOND OUR CONTROL.

ALCHEM

SOLUTION PREPARATION

Solutions of ALCHEM 8C26 may be quickly and easily prepared at concentrations of 0.5–1.0% using fresh water at temperatures of 8–45°C. The warmer temperatures substantially reduce mixing time.

Premix ALCHEM 8C26 in the drum with a drum mixer for a minimum of one hour before initial use and 5–10 minutes before each subsequent use.

Add water to the make-up tank until the blades of the agitator are covered. Start the mixer and wait for it to draw a vortex. Quickly add the ALCHEM 8C26 to the vortex of the water, and continue to add water until the tank is full. When the tank is filled, continue mixing the solution for 10–25 minutes.

Solutions of ALCHEM 8C26 are not corrosive. Carbon steel may be used for tank and pump construction. Galvanized metals and natural or synthetic rubber should be avoided.

ALCHEM 8C26 solutions may be used immediately after preparation.

Automatic feed systems are available from Alchem. Your Alchem Representative will assist you in the details for such a system.

HANDLING

As with all chemicals, ALCHEM 8C26 should be handled with reasonable care. Avoid contact with skin, eyes, and clothing. In case of contact with skin, wash with water. For eyes, wash with water for 15 minutes; call a physician. Do not take internally. For spills, neat product, – contain on absorbent material; solution – flush with water until slippery conditions desist.

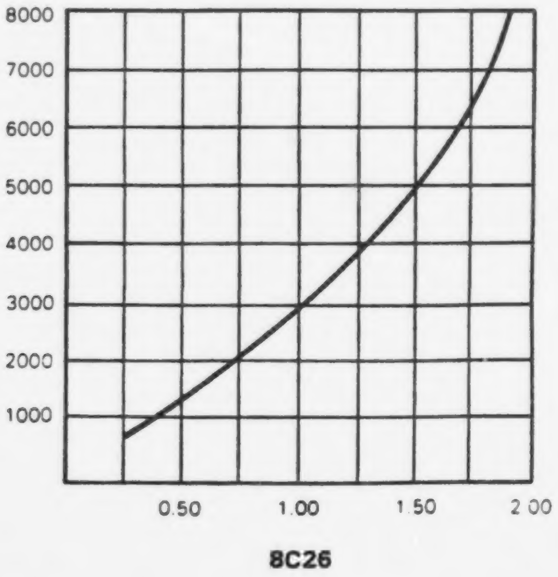
SHIPPING AND STORAGE

ALCHEM 8C26 is shipped in 210-L non-returnable steel drums. Bulk shipments are also available. Your Alchem Representative will assist you in designing the proper bulk handling system.

Storage for more than one year is not recommended. Storage temperature is 22°C. Temperatures between 3 and 35°C are not harmful; however, freezing and overheating should be avoided.

HCL 8206

FIGURE 1 – Viscosity (mPa·s)
ALCHEM 8C26 in Tap Water (25°C)



ALCHEM INC.

MATERIAL SAFETY DATA SHEET

P.O. BOX 5002 BURLINGTON, ONTARIO L7R 3Y9 TEL. NO. (416) 632-8791

* * * * * * * *

PRODUCT TRADE NAME: Alchem 8C26 CHEMICAL FAMILY: Latex Polyelectrolyte

HAZARDOUS INGREDIENTS

Petroleum Distilates <25%

PHYSICAL DATA

SOLUBILITY IN WATER: Viscosity limited up to 1.5%.

SPECIFIC GRAVITY @ 25°C: 1.09

pH: 8.1 (1% solution)

APPEARANCE & ODOUR: Opaque yellowish white liquid with hydrocarbon odour.

FIRE & EXPLOSION DATA

FLASH POINT (METHOD USED): >100°C (TCC)

EXTINGUISHING MEDIA: Foam, CO_2, Dry Chemical

SPECIAL FIRE FIGHTING PROCEDURES: Protect firefighters from combustion products.

UNUSUAL FIRE & EXPLOSION HAZARDS: None

REACTIVITY DATA

STABILITY: Stable

CONDITIONS TO AVOID: None

INCOMPATIBILITY (MATERIALS TO AVOID): None

HAZARDOUS DECOMPOSITION PRODUCTS: Products of incomplete hydrocarbon combustion.

HAZARDOUS POLYMERIZATION: Will not occur.

DATE: 1984-04-11 ALC

HEALTH HAZARD DATA

THRESHOLD LIMIT VALUE (TLV): None established.

TOXICITY RATING: Practically non-harmful. Exposure will result in no adverse effects except in abnormal circumstances.

SKIN IRRITATION: Slightly irritant. May cause transient dryness.

EYE IRRITATION: Practically non-irritant.

EMERGENCY & FIRST AID TREATMENT:

INHALATION: Due to low volitility of petroleum distilates, little inhalation hazard exists with normal use.

SKIN & EYE CONTAMINATION: Flush eyes with plenty of water for 20 minutes holding eyelids open. Call a physician. Wash off skin with soap and water.

INGESTION: Do not induce vomiting. Call a physician.

SPECIAL PROTECTION INFORMATION

RESPIRATORY PROTECTION: None normally required.

VENTILATION: No special requirements.

EYE PROTECTION: Goggles or face shield.

PROTECTIVE GLOVES: Synthetic rubber or similar.

OTHER PROTECTIVE EQUIPMENT: None

SPECIAL REQUIREMENTS

PRECAUTIONS IN HANDLING AND STORING: None

OTHER PRECAUTIONS: Always clean spills thoroughly to avoid hazardous slippery conditions.

SPILL AND LEAK PROCEDURES

STEPS TO BE TAKEN IN THE EVENT OF A SPILL OR RELEASE: Neat product, contain on an absorbent material. Solutions, flush away with plenty of water.

ENVIRONMENTAL EFFECTS: 96 h LC_{50} = 160 mg/L salmo gardneri

NEUTRALIZING CHEMICALS: N.A.

WASTE DISPOSAL: Recycle or complete combustion.

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Appendix 3

Firing temperature curves for Phases I and II

* T° scale linear from 0 to 2500°F

01 : Hearth layer.

02 : Bottom of the bed (1" above interface).

03 : Center of the bed.

04 : Top of the bed (1" in the bed).

05 : Gas T° under the bed (inlet gas for UDD and cooling zones and oulet gas for the others).

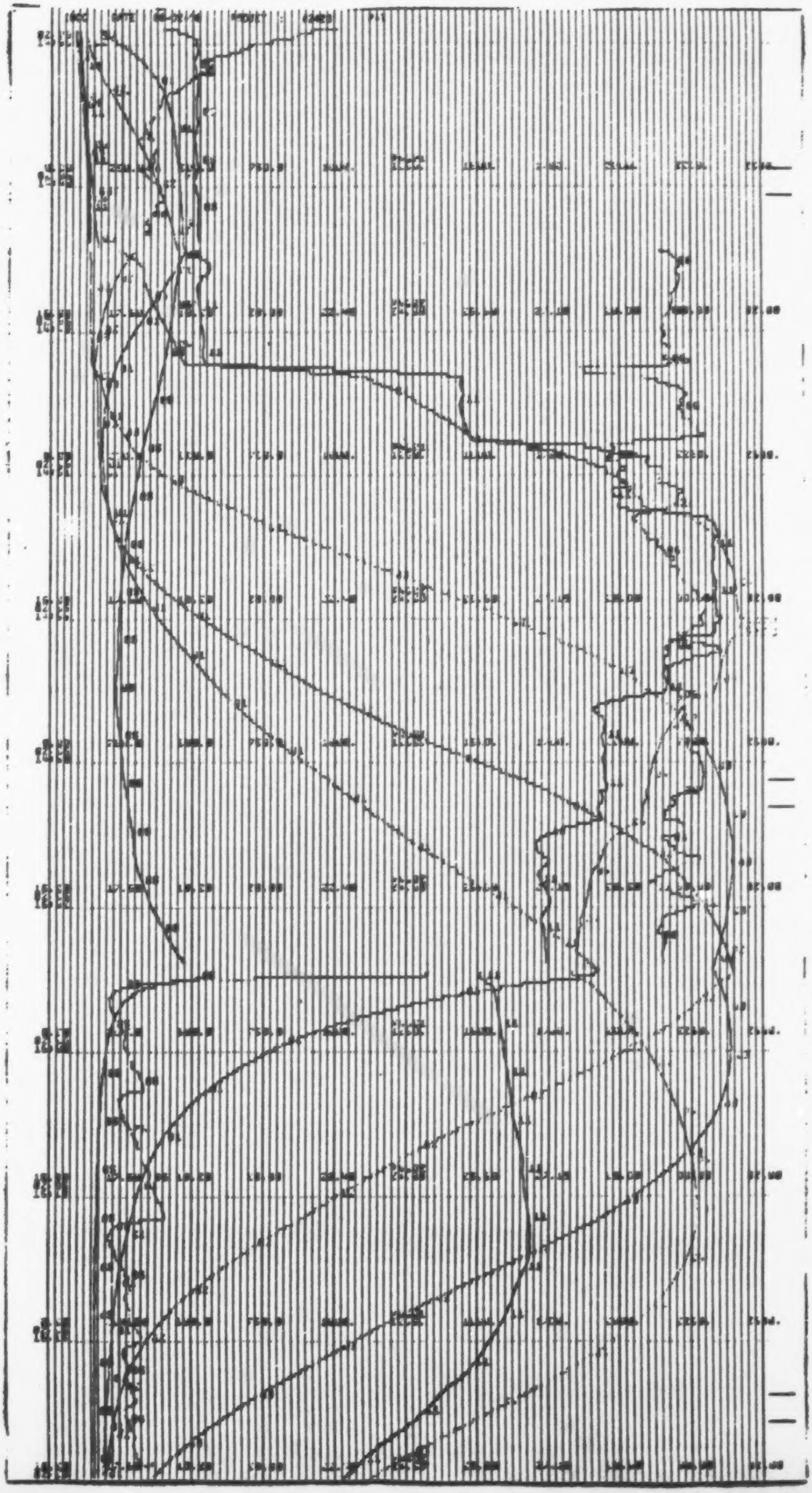
11 : Gas T° above the bed (outlet gas for UDD and cooling zones and inlet gas for the others).

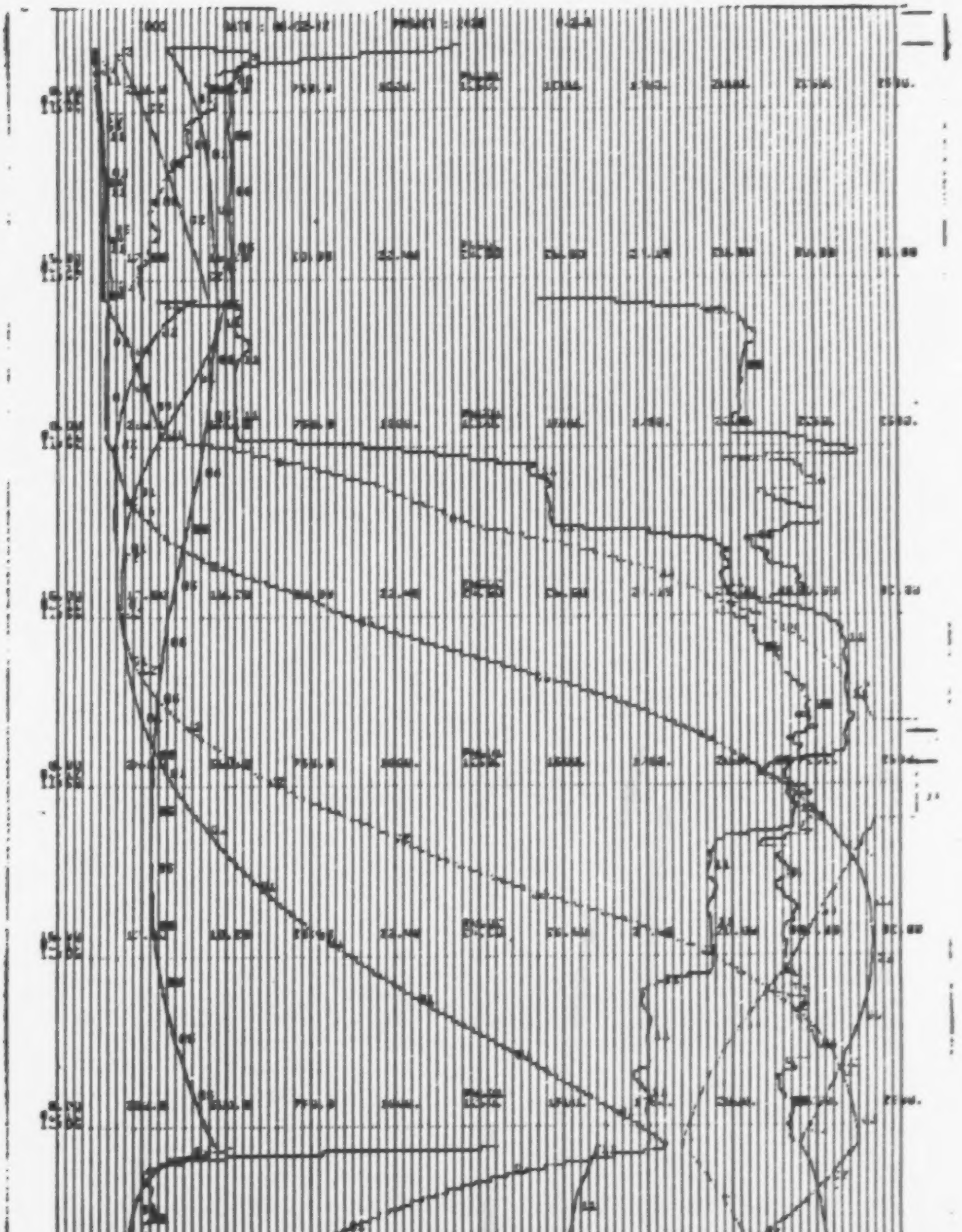
06 : Pressure drop across the bed (linear scale from -25 to +25" H_2O).

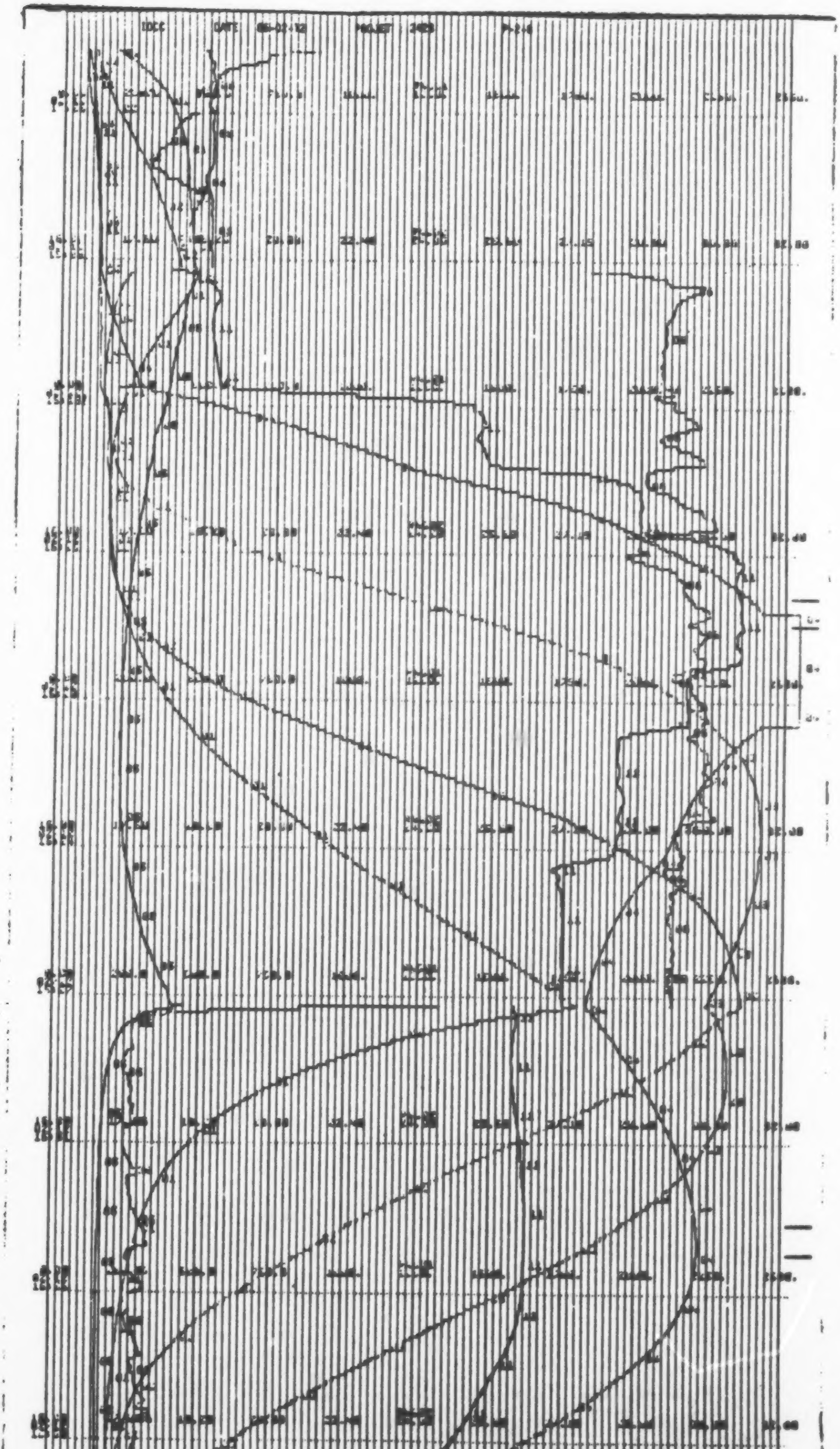
Phase I

Test series # 1, 2 and 3

P-1. P-2A to 2C, P-3A to 3D



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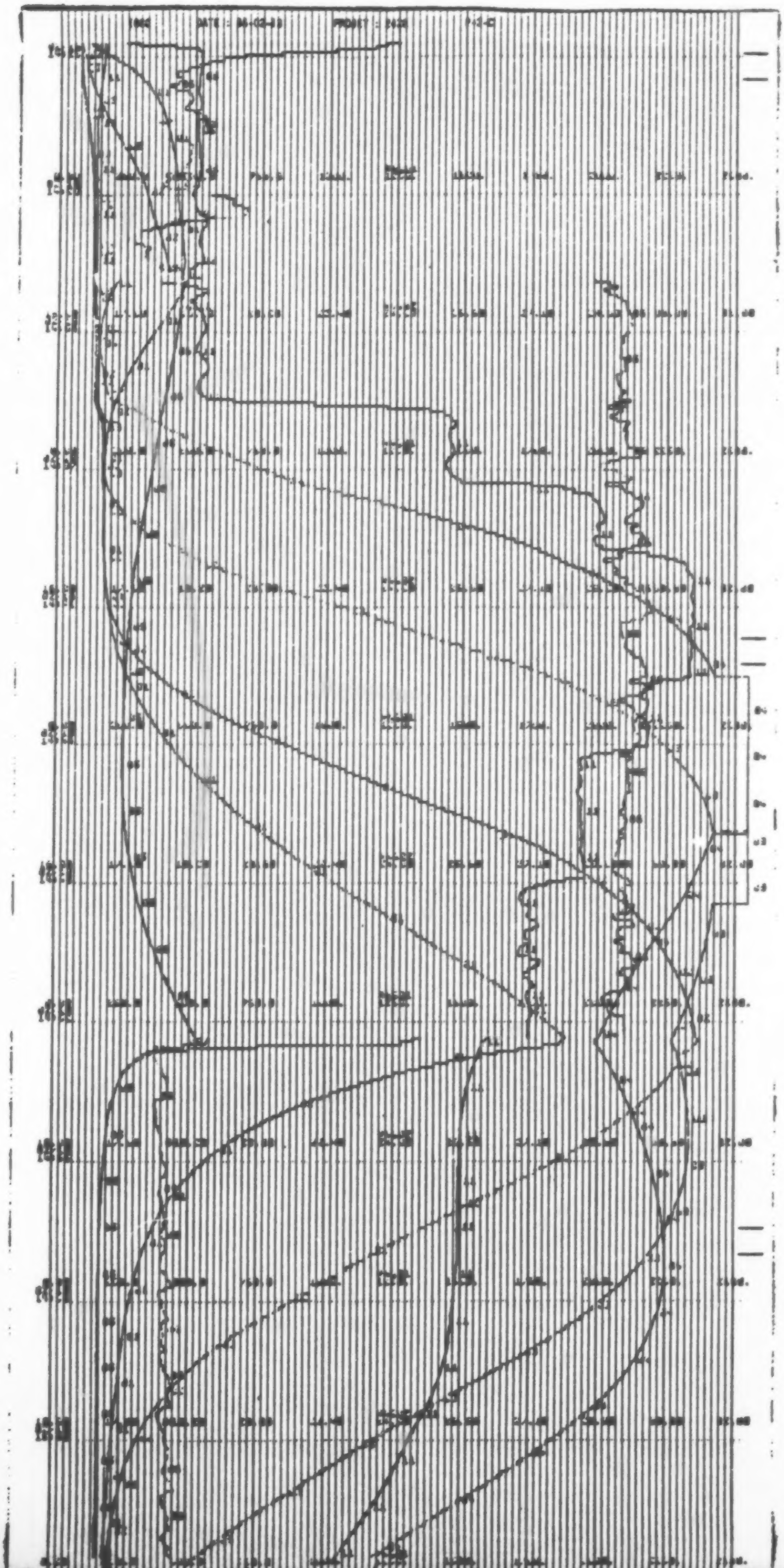
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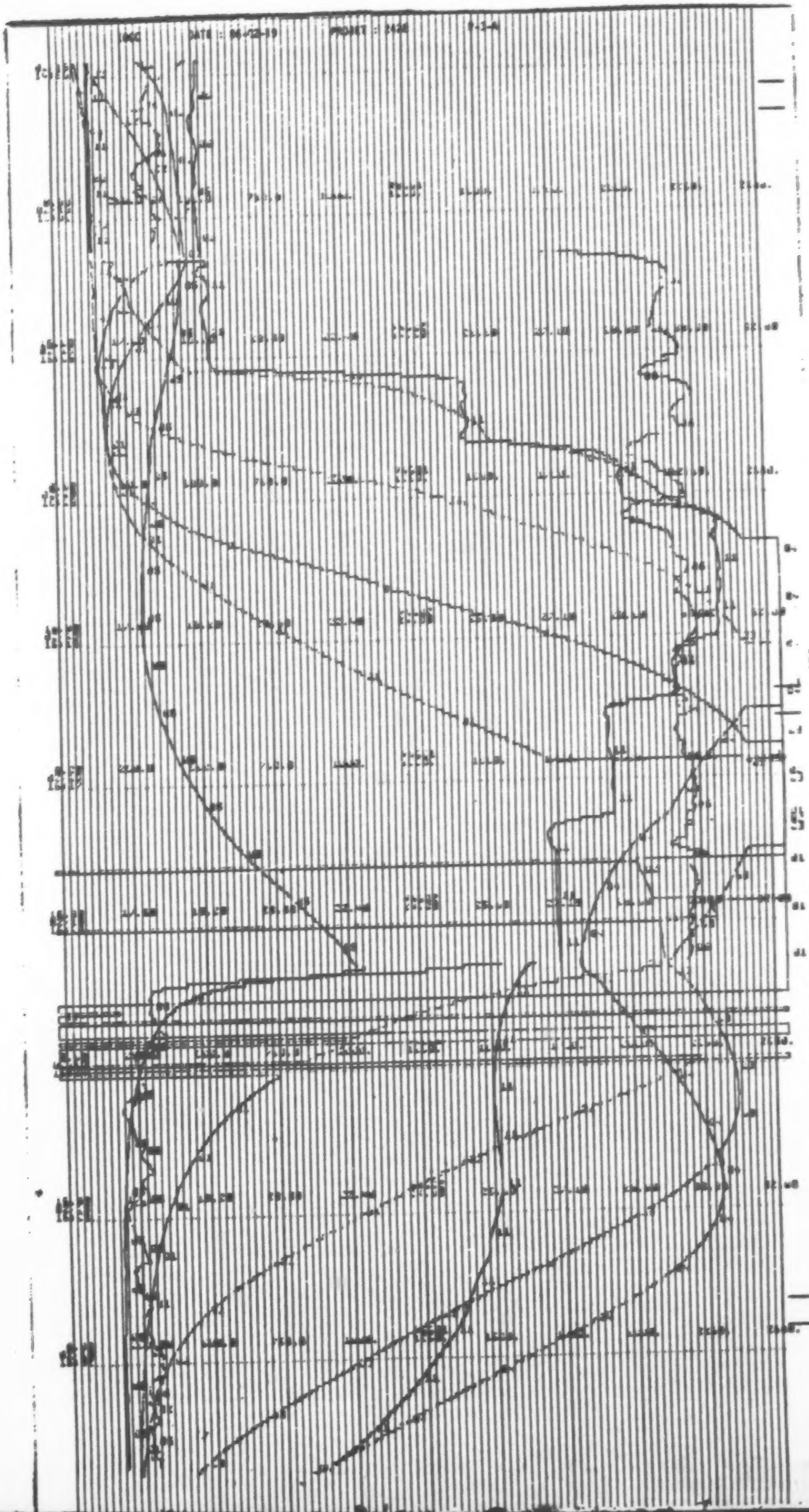
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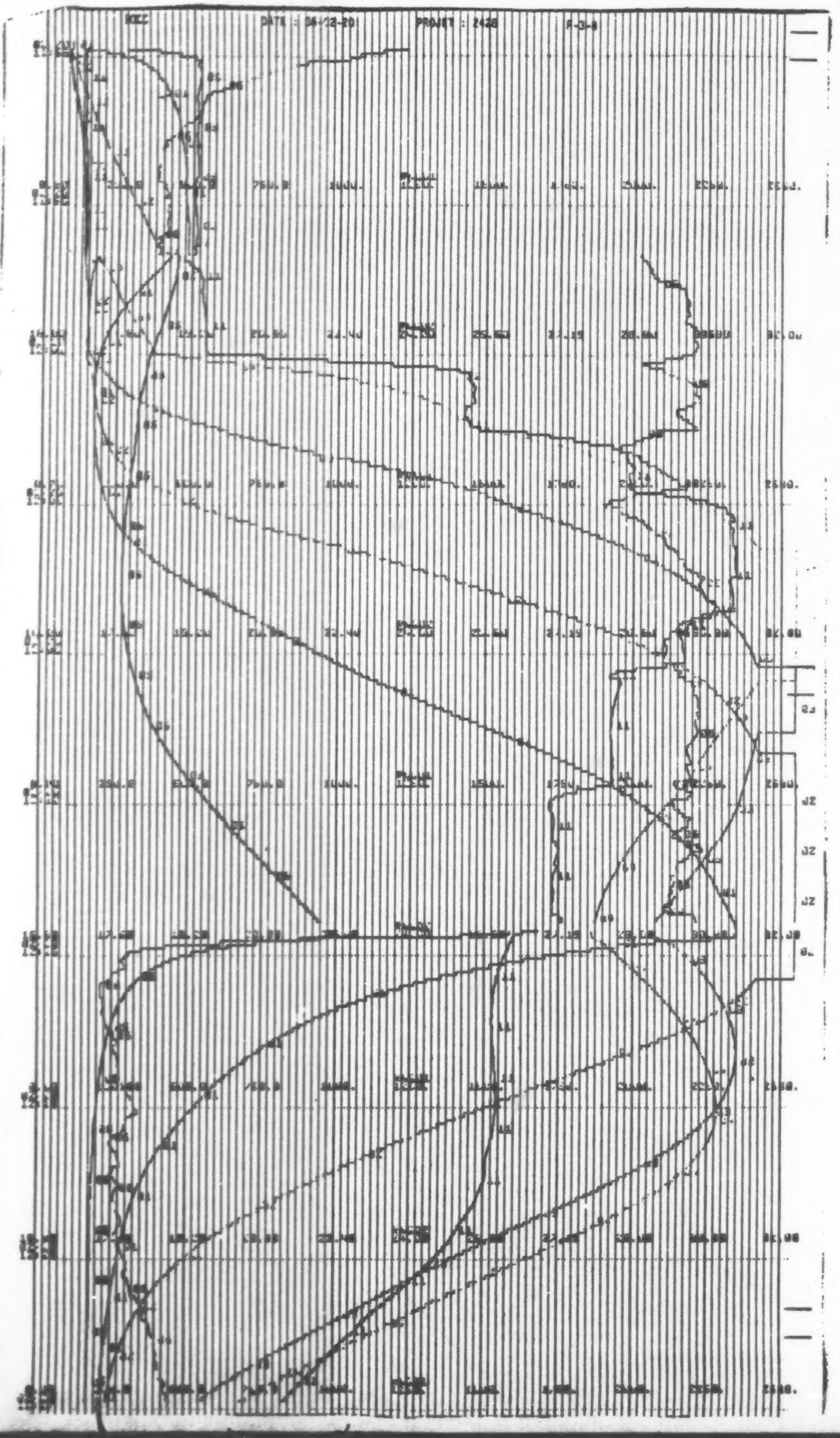
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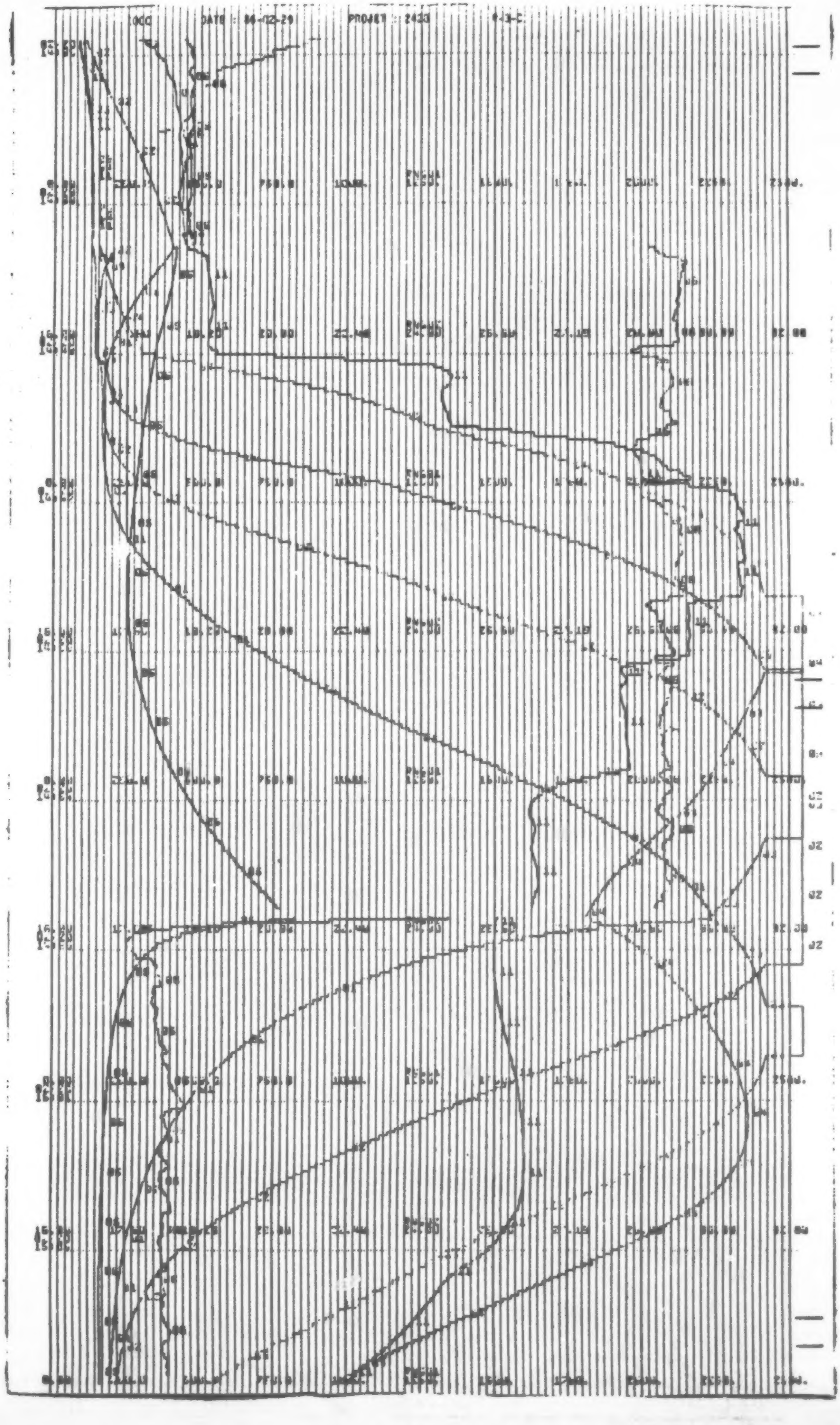
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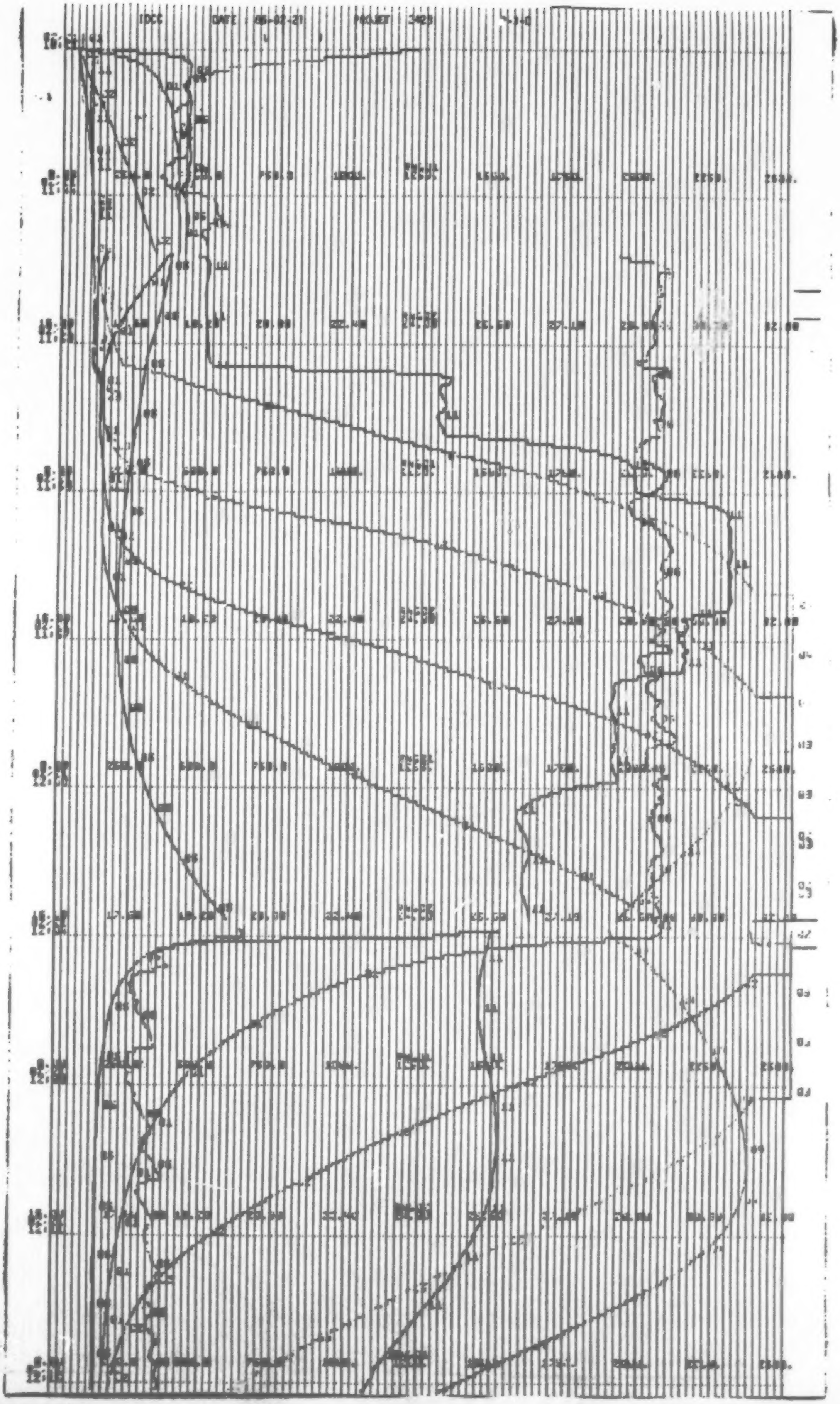
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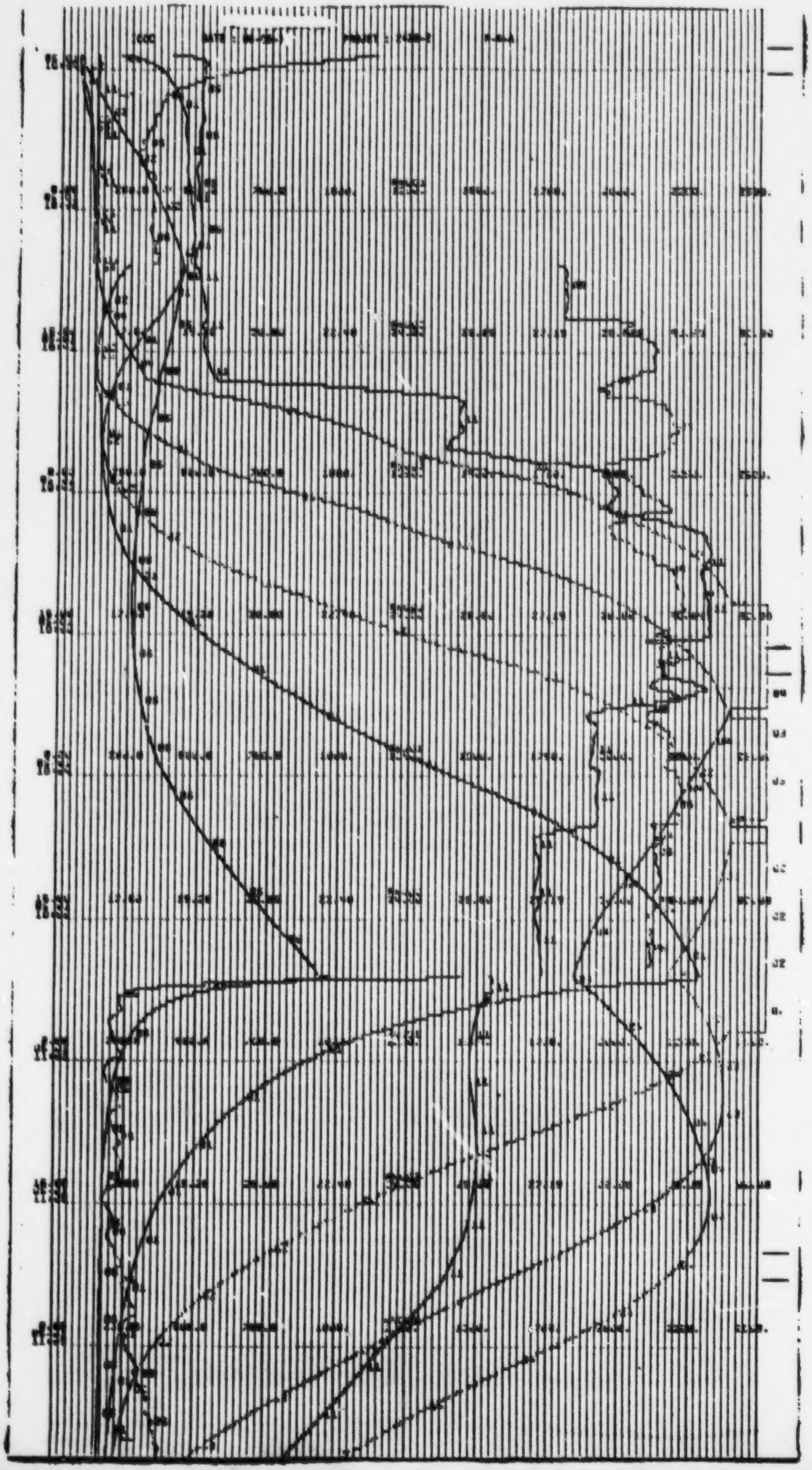
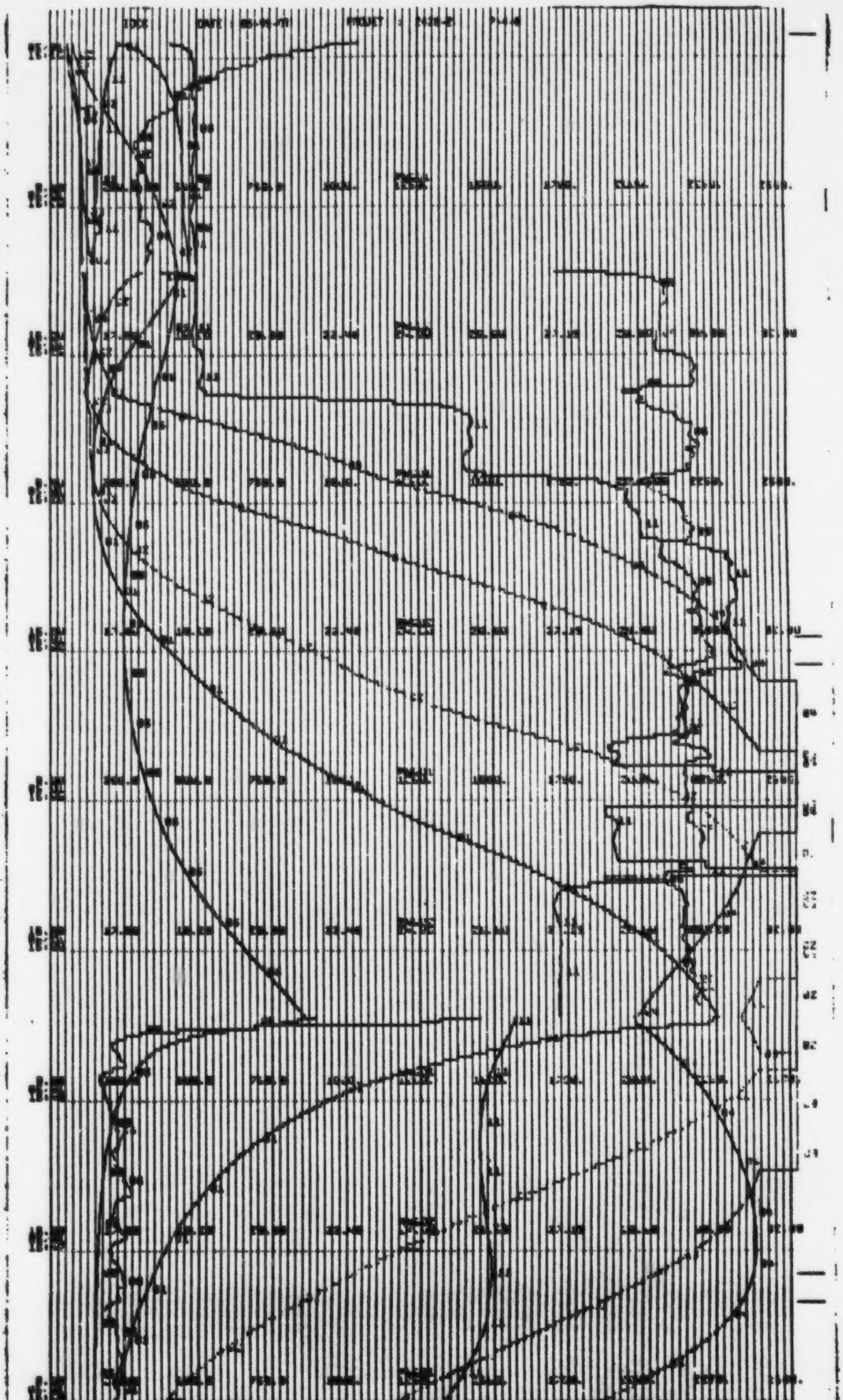
22.40
24.00
25.60
27.20
28.80
32.00

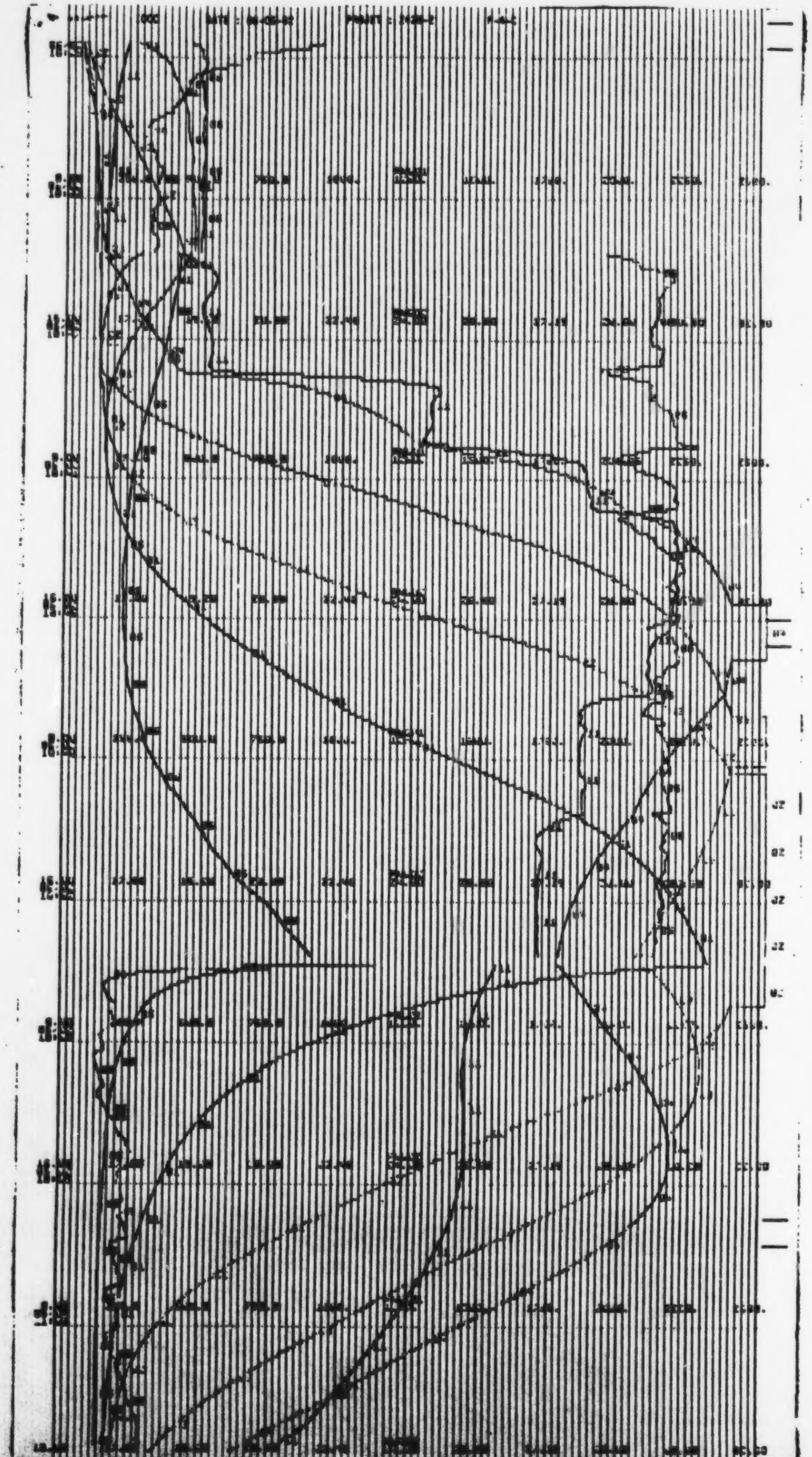
Phase II

Test series # 4, 5, 6 and 7

P-4A to 4D, P-5A to 5C, P-6A and 6B, P-7A to 7C



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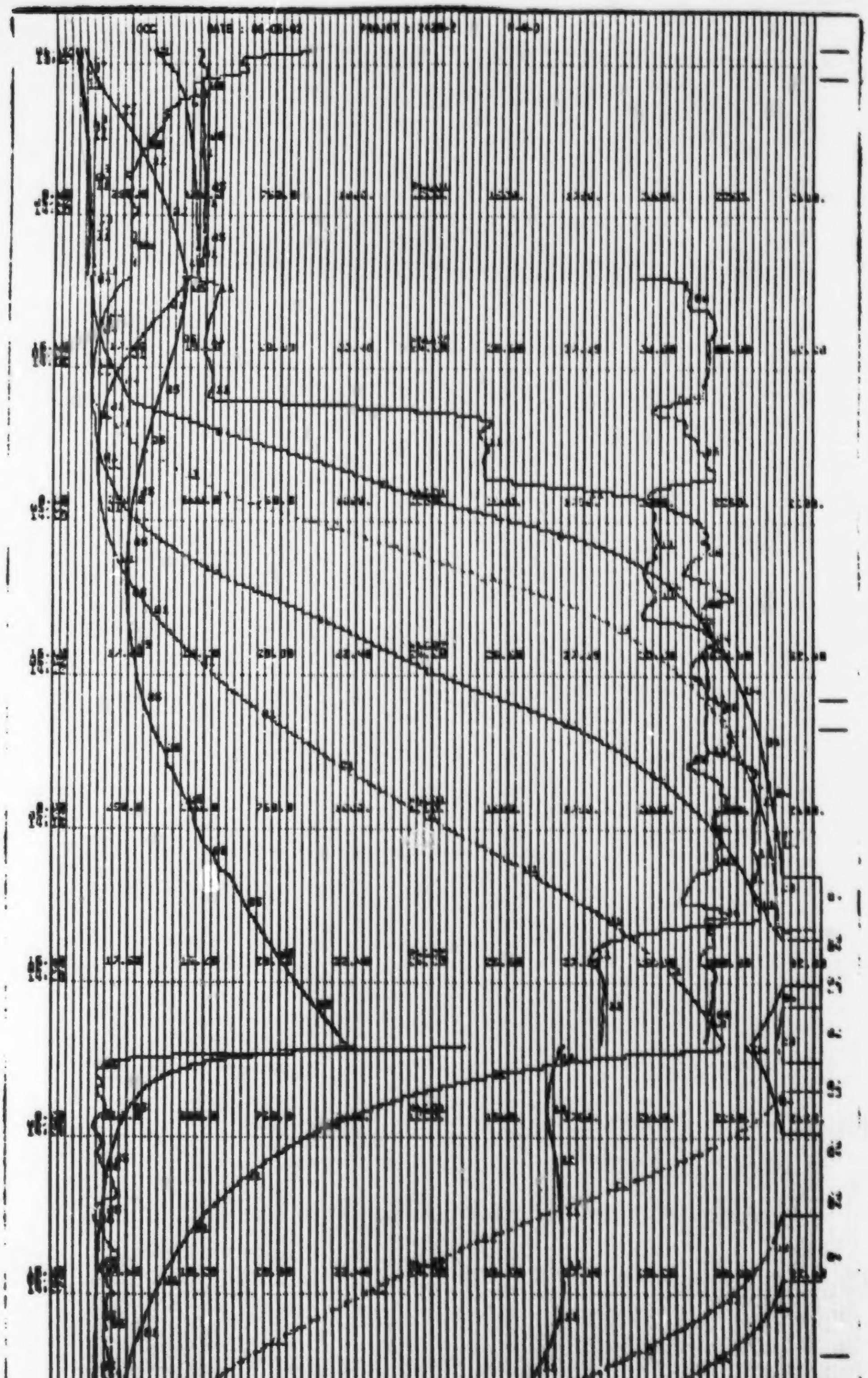
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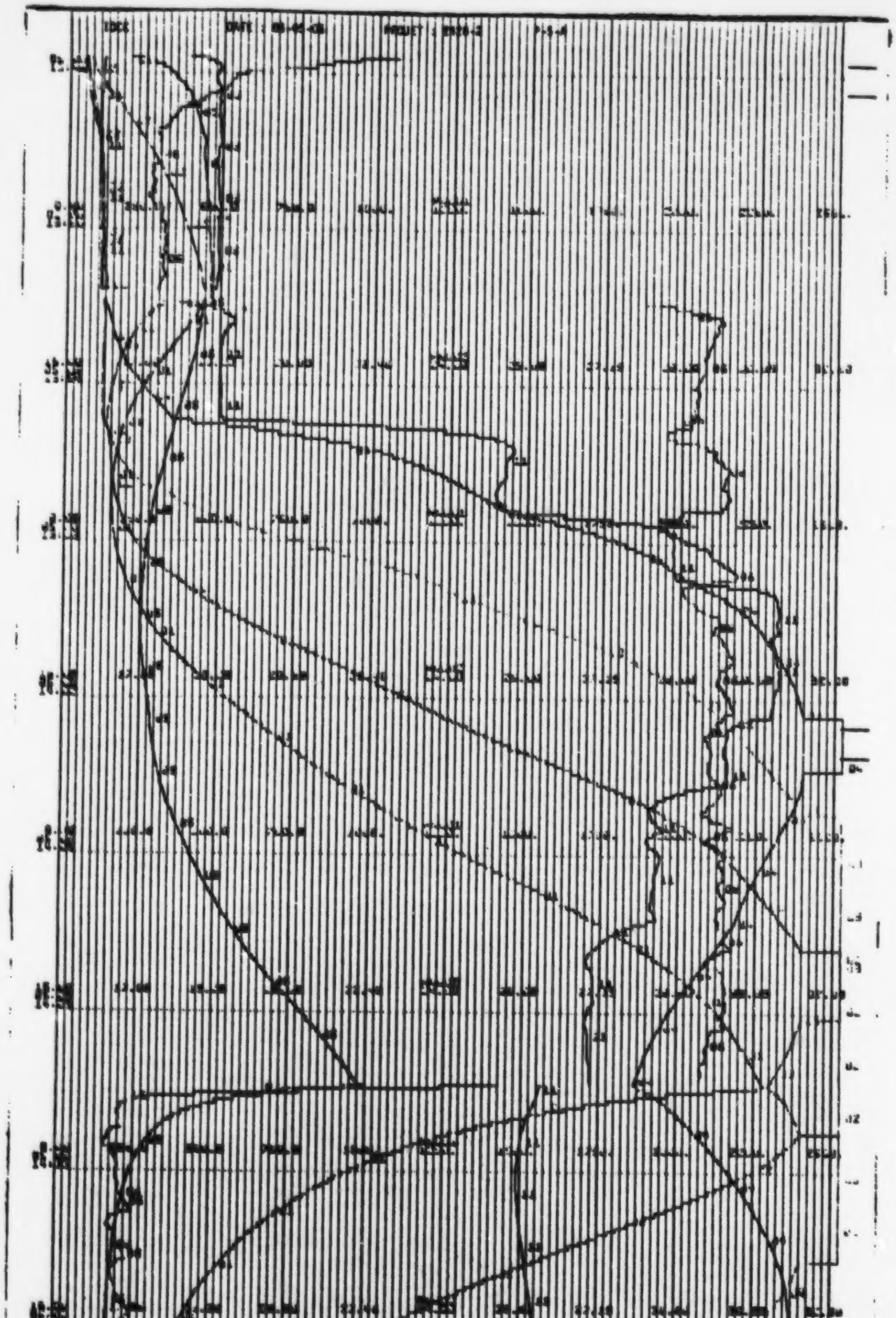

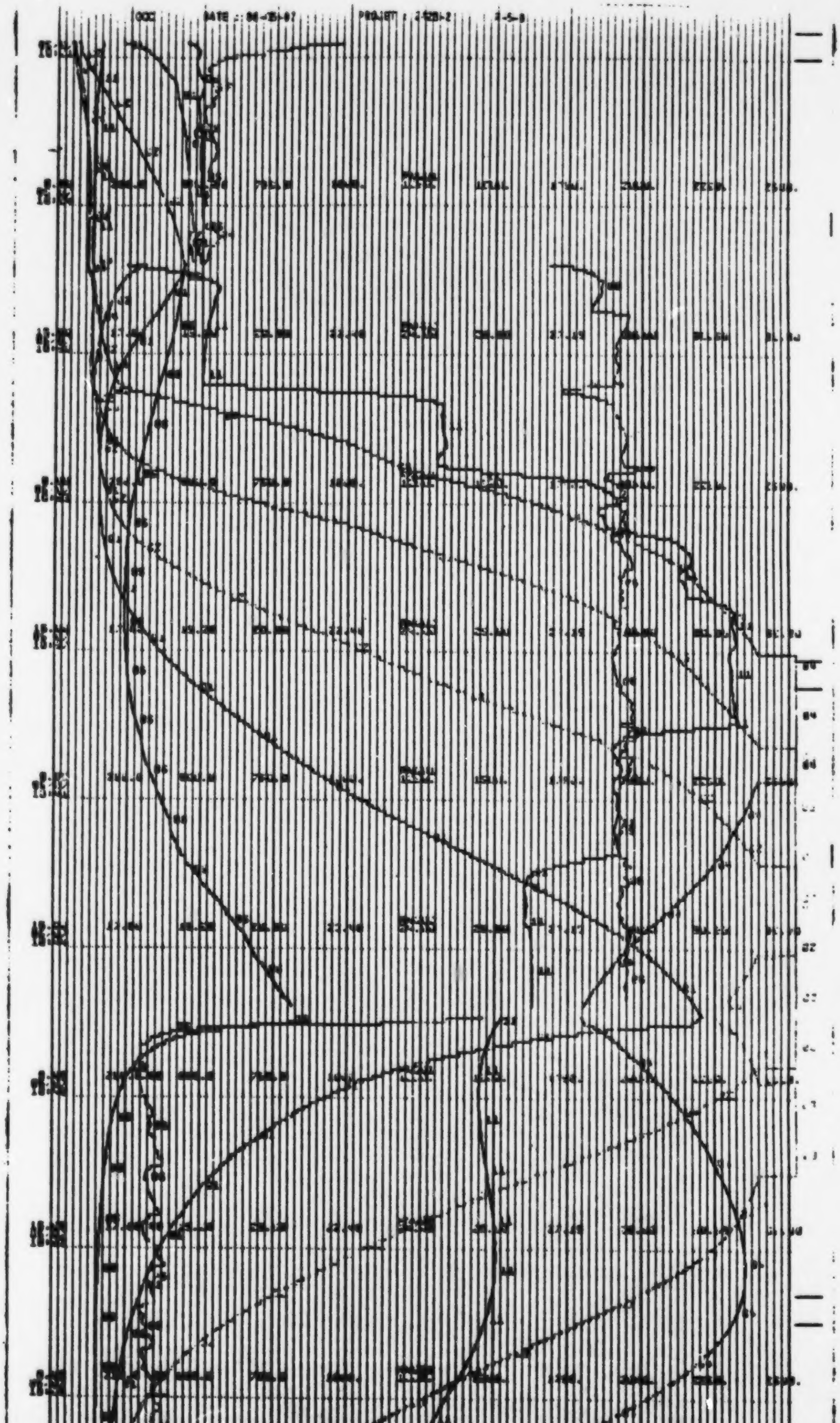
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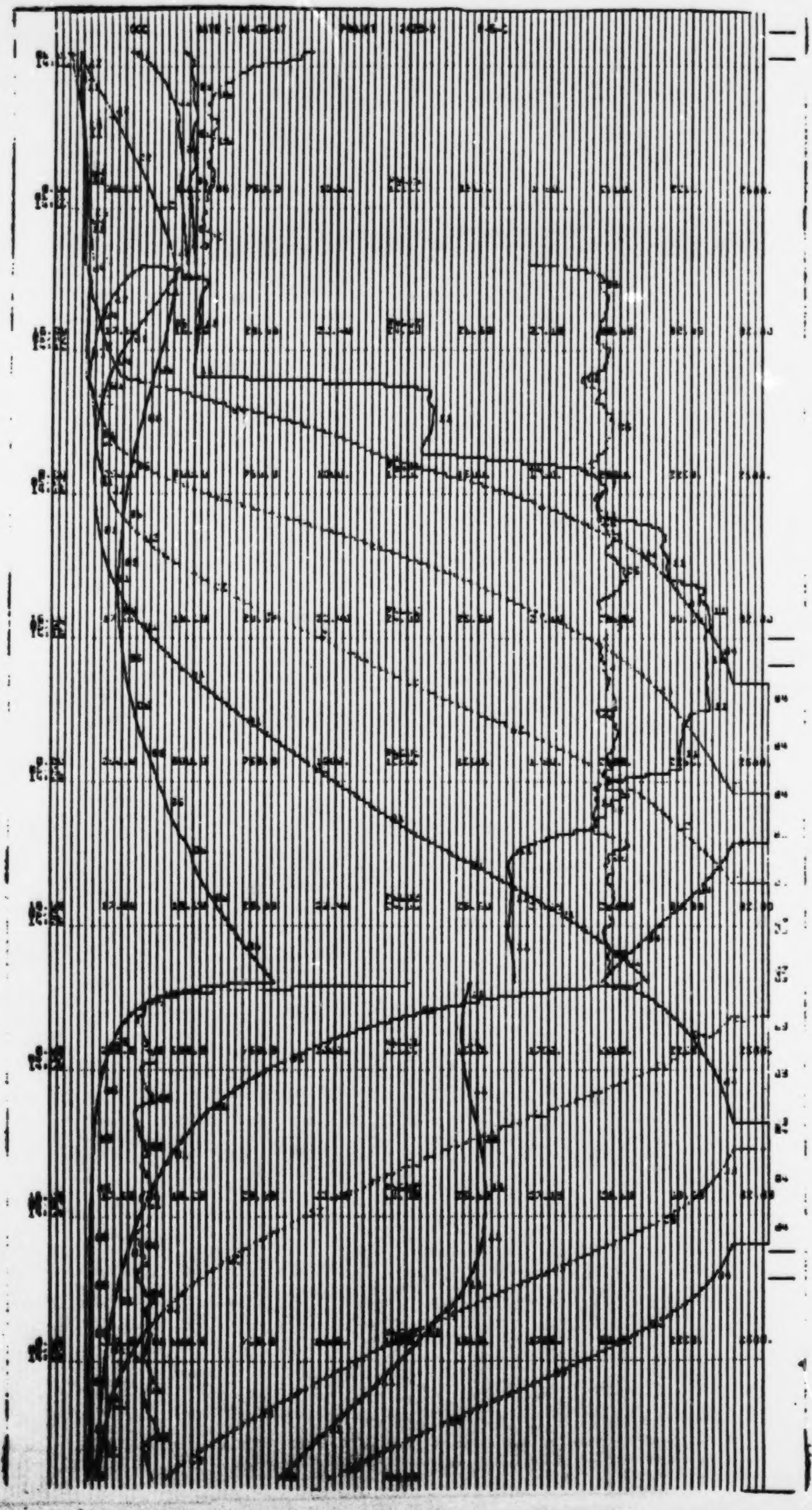

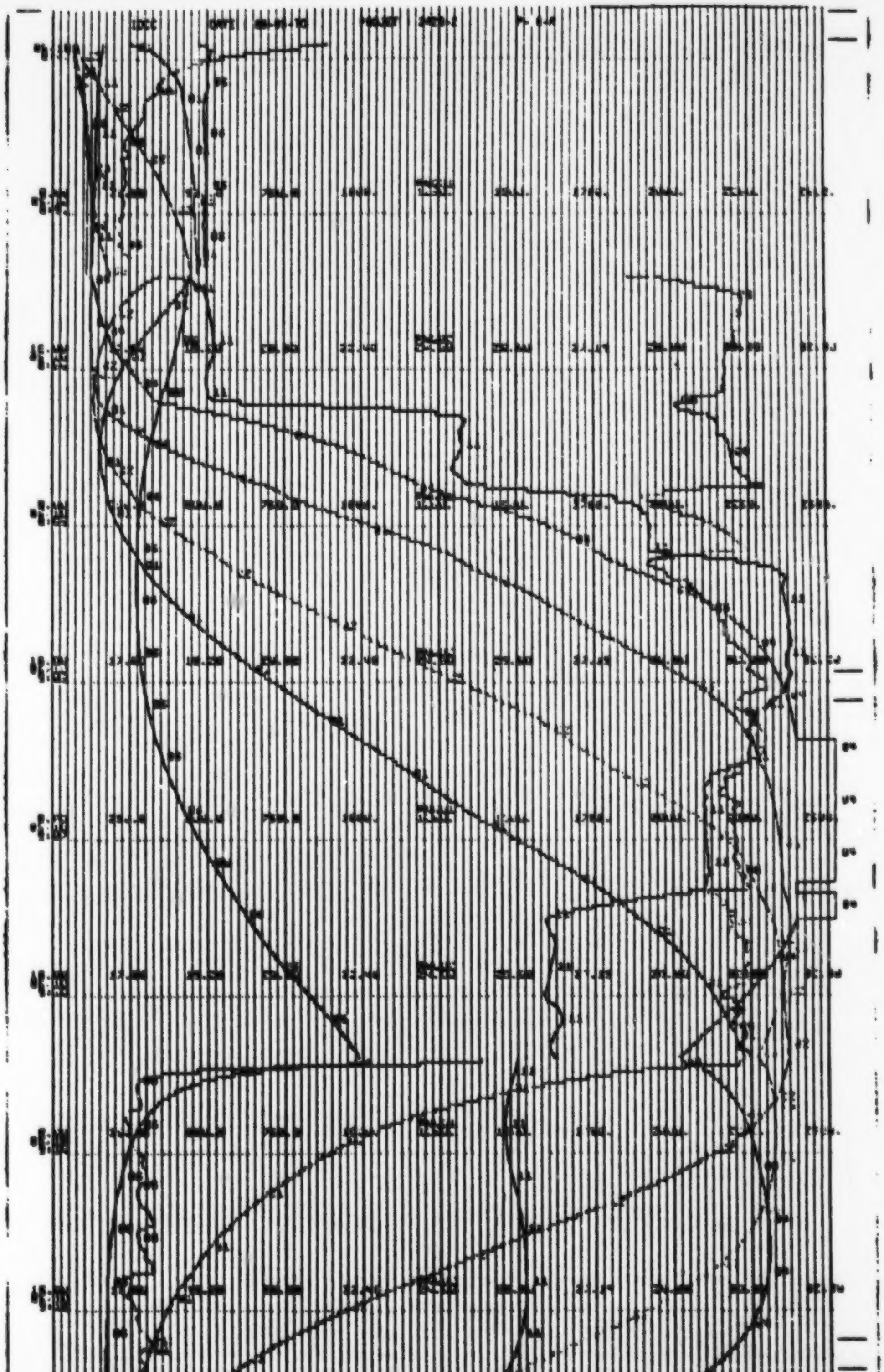

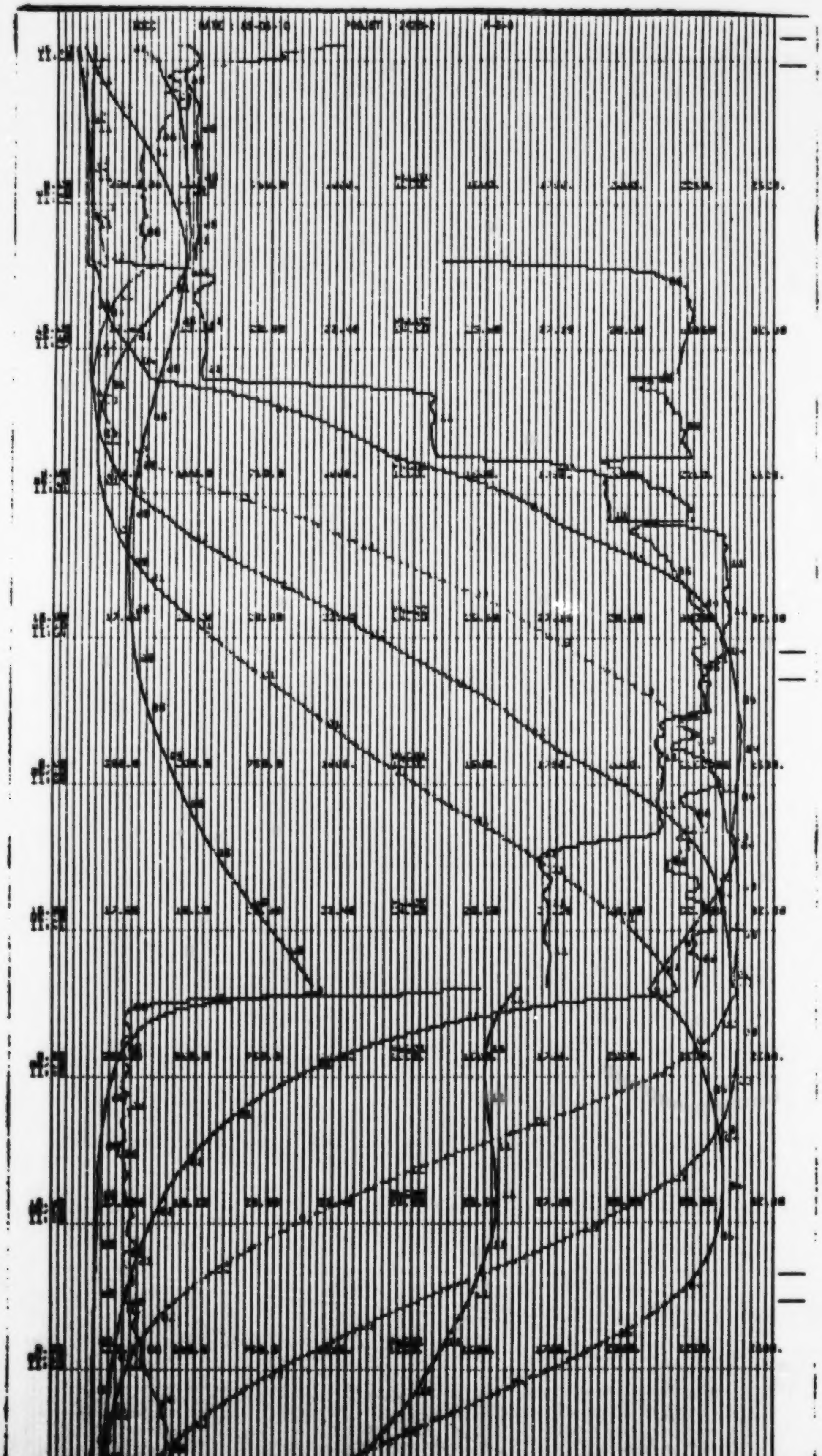

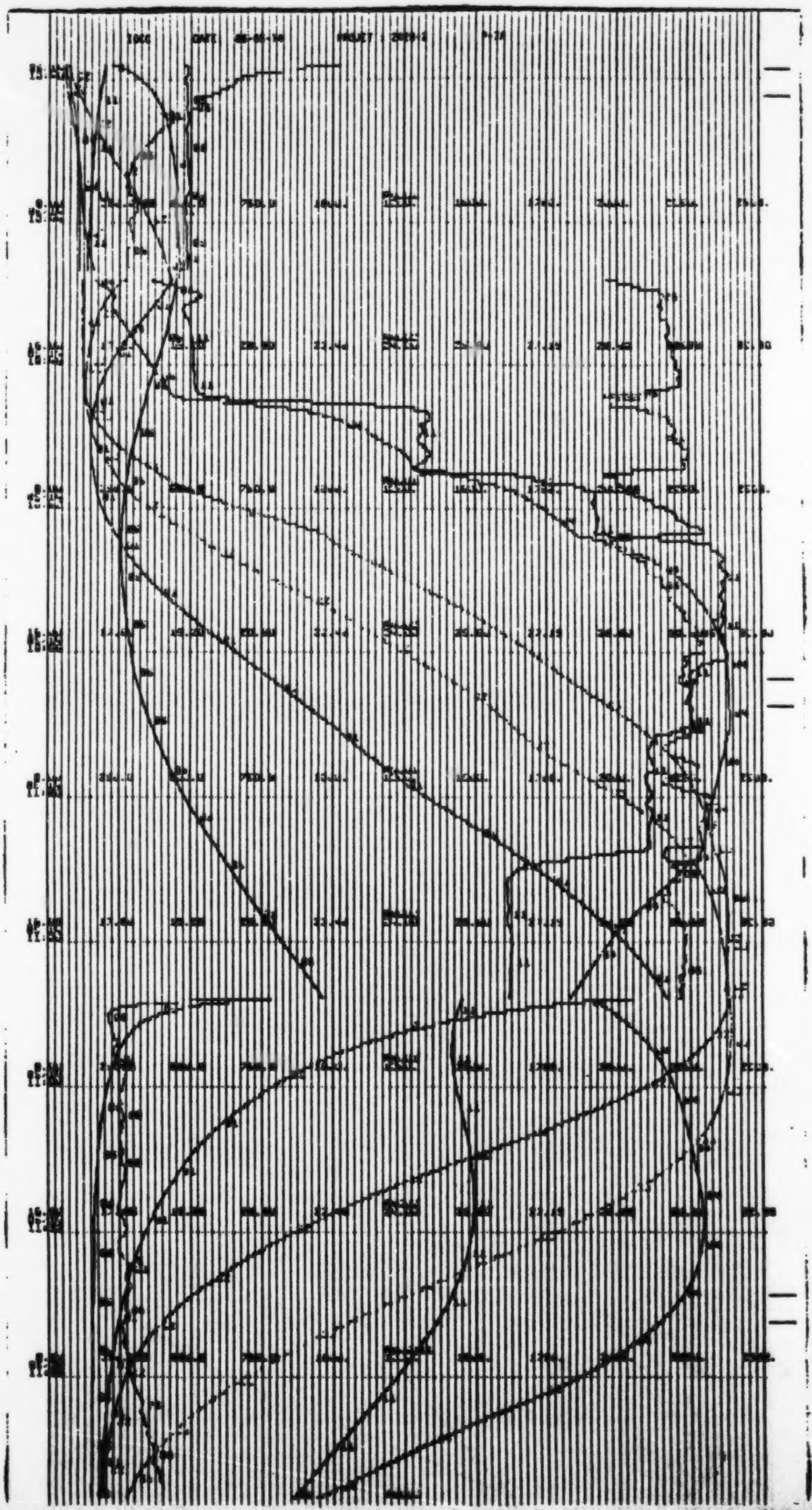
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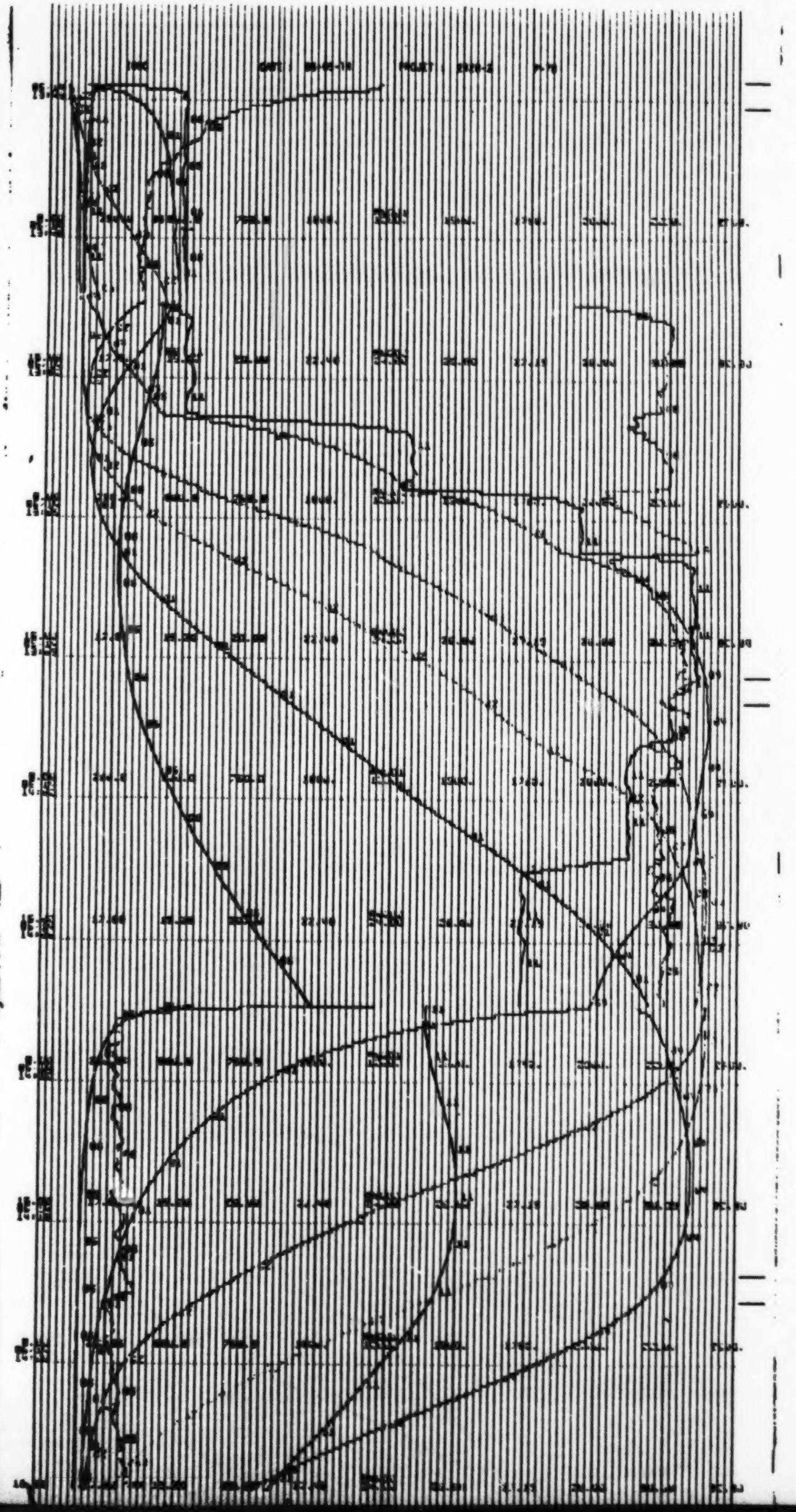

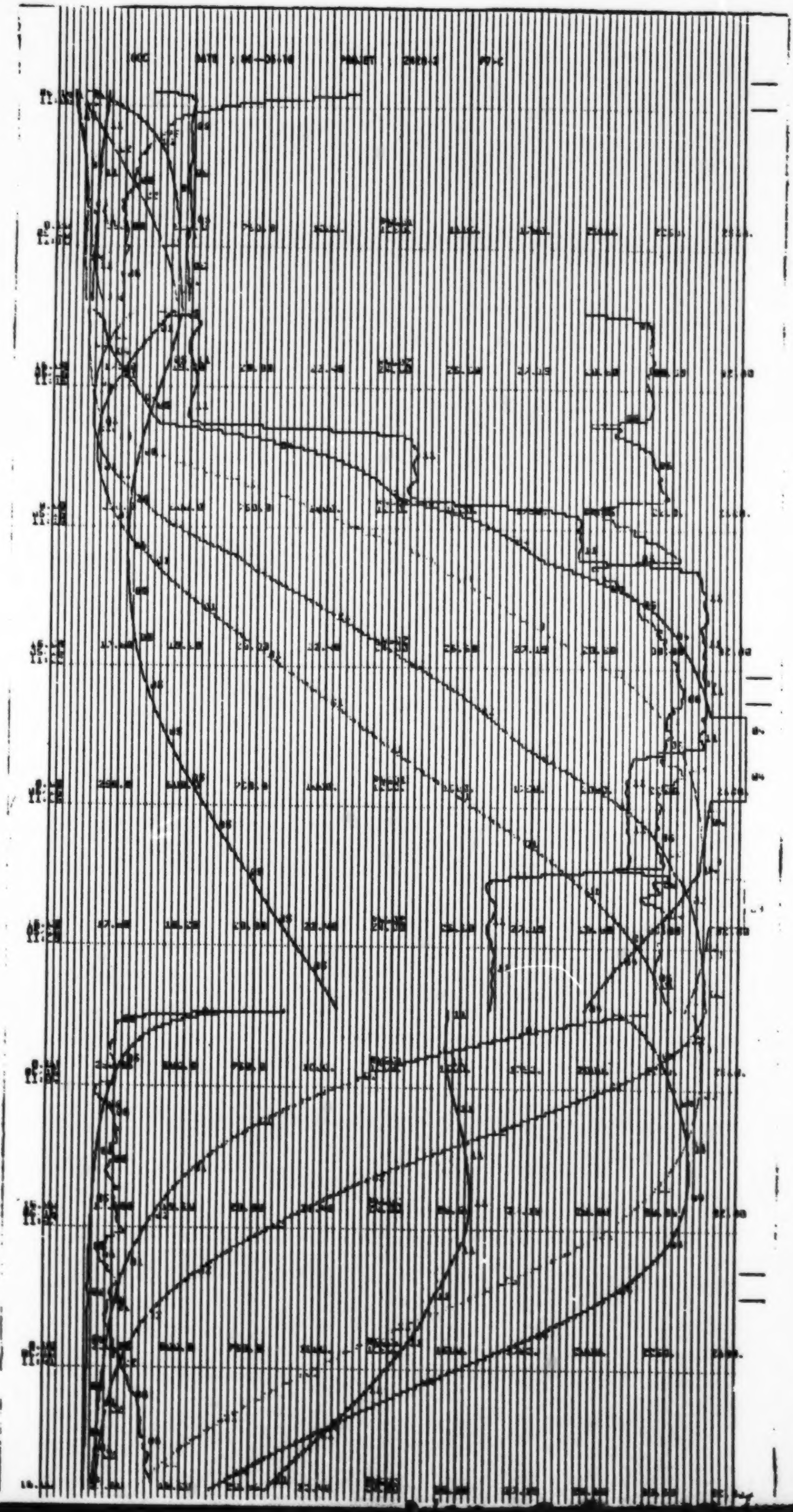
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Appendix 4

Mineralogical examination of fired pellets

P-1 : 0.85% bentonite

P-2B : 0.125% Alchem

P-3D : 1.0% Peat moss (dry basis)
0.1% NaOH

DIRECTION DE LA
RECHERCHE MÉTALLURGIQUE
(# 2428)

PROJECT: 85-MI-039

TEXTURAL COMPARISON OF THREE IRON PELLET TYPES

BY

BERNARD KIELLER, MINÉR.

APRIL 1986

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Complexe scientifique
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DIRECTION DE L'ANALYSE MINÉRALE

Project: 85-Mi-039

TEXTURAL COMPARISON OF THREE IRON PELLET TYPES

Copie no: __

Report for:

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Usine-Pilote
Direction de la Recherche métallurgique
Centre de Recherches minérales

Compiled by:

Bernard Kieller, minéralogiste
Responsable de la division
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Signature:

Approved by:

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et de la Minéralogie

Signature: Simon Turmel.

Authorized by:

Marc Pichette, chim.
Directeur de la direction de
l'Analyse minérale

Signature: 86-05-06

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1. INTRODUCTION 1

2. CONCLUSIONS 2

3. PROCEDURE 2

4. DESCRIPTIVE MINERALOGY 3

5. DISCUSSION 7

ANNEX - PHOTOMICROGRAPHS

1. INTRODUCTION

Mr. Guy Paquet, from C.R.M.'s Pilot Plant, submitted three (3) I.O.C.C. pellet samples which contained three different additives in the green balling stage.

The designations of each sample according to its additive is as follows.

Designation	Additive
P-1	Bentonite
P-2B	Alchem 8-C-26
P-3D	Peat

2. CONCLUSIONS

The use of three different additives in the iron pellets has produced marked differences in the mineralogical composition and the texture of the pellets.

Reduction of hematite in cores occurred in all three pellet types to a varying degree. Reoxydation was also variable amongst the three types.

Firing temperatures were lowest in bentonite pellets and highest in peat pellets.

3. PROCEDURE

Fifteen to twenty equatorial pellet slices of each sample were used to prepare a polished section. The sections expose the maximum diameter of the pellet slices perpendicular to the slice direction.

The pellet textures are studied with a reflected light polarizing microscope.

4. DESCRIPTIVE MINERALOGY

Tables 1 to 3 resume the composition and the textural features observed in pellets of the three samples.

The textural types of the pellets indicated in the tables are according to the following bonding features as related to the firing intensity.

Type	Hematite(-magnetite) bond texture
O	Interlocked hematite grains; no adhesion
A	Bridging between hematite grains
A/B	*
B	Adhesion between hematite grains; little slag
B/C	*
C	Hematite grains are bonded by slag; little adhesion
C/D	*
D	Strong slag bonding with much hematite recrystallization
M	Mozaïc hematite texture due to reduction of hematite to magnetite and partial or total reoxydation accompanied by intergranular slag penetration

* Intermediary types

Note: Type M occurs always in the cores of the pellets.

Photomicrographs in the annex show typical textures in the samples.

TABLE 1

MINERALOGICAL DETERMINATION

DESIGNATION: P-1 (Bentonite)

MAJOR MINERALS (>10%)	MINOR MINERALS (1-10%)
Hematite	Quartz Slag Magnesioferrite -pseudomorphic -intergranular (less) Magnetite

ACCESSORY MINERALS (<1%)

Pseudobrookite (traces)

TEXTURAL DESCRIPTION AND/OR REMARKS

TEXTURAL TYPE: zoned (in order of abundance)

Zone 1: M (core); more than half of the pellets enclose residual magnetite in variable amounts (>10% in two pellets where the texture is rather a C/M type).

Zone 2: C (exterior)

Texture between pellets - heterogeneous

TYPICAL SIZE OF HEMATITE RECRYSTALLIZATION (μm): 4 (zone 1), 3 (zone 2)

TYPICAL QUARTZ REACTION RIM WIDTH (μm): 2

SLAG POOL DIAMETER (μm): <2 (zone 1), 3 (zone 2)

GEOLOGICAL/SPECIMEN NAME

Iron pellets

TABLE 2

MINERALOGICAL DETERMINATION

DESIGNATION: P-2B (Alchem 8-C-26)

MAJOR MINERALS (>10%)	**MINOR MINERALS (1-10%)**
Hematite	Quartz Slag Magnesioferrite -pseudomorphic -intergranular (very little)

ACCESSORY MINERALS (<1%)

Magnetite (traces), iron (traces)

TEXTURAL DESCRIPTION AND/OR REMARKS

TEXTURAL TYPE: zoned (in order of abundance)
Zone 1: C/D (exterior)
Zone 2: M (core)
Texture between pellets is heterogeneous; all pellets are more porous than pellets in sample P-1B.

TYPICAL SIZE OF HEMATITE RECRYSTALLIZATION (μm): 3 (zone 1), 3 (zone 2)
TYPICAL QUARTZ REACTION RIM WIDTH (μm): 2
SLAG POOL DIAMETER (μm): 3 (zone 1), 2 (zone 2)

GEOLOGICAL/SPECIMEN NAME

Iron pellets

TABLE 3

MINERALOGICAL DETERMINATION

DESIGNATION: P-3D (Peat)	
MAJOR MINERALS (>10%)	**MINOR MINERALS (1-10%)**
Hematite	Slag Magnesioferrite -pseudomorphic (traces) -intergranular
ACCESSORY MINERALS (<1%)	
Magnetite, quartz (traces)	
TEXTURAL DESCRIPTION AND/OR REMARKS	
TEXTURAL TYPE: zoned (in order of abundance) Zone 1: M (core); majority of grains contain a very little residual magnetite. Zone 2: D (exterior) Texture between pellets - homogeneous; pellets are very porous; concentric banding in pellet texture is somewhat evident. TYPICAL SIZE OF HEMATITE RECRYSTALLIZATION (μm): 5 (zone 1), 4 (zone 2) TYPICAL QUARTZ REACTION RIM WIDTH (μm): 4 SLAG POOL DIAMETER (μm): 10 (zone 1), 5 (zone 2)	
GEOLOGICAL/SPECIMEN NAME	
Iron pellets	

5. DISCUSSION

As the mineralogical composition and textures indicate in the tables, the three pellet samples are distinct one from the other.

Magnetite is the most abundant in sample P-1 whereas quartz is the least abundant in sample P-3D. Much hematite was reduced to magnetite in sample P-1. Some of this magnetite did not reoxidize and is seen as residual magnetite in hematite-magnetite particles. A considerable amount of hematite was also reduced to magnetite in sample P-3D. However a larger quantity was reoxidized to hematite, as indicated by the presence of the textural type M, than in sample P-1. Least reduction occurred in sample P-2B.

Quartz is less abundant in sample P-3D because the pellets have been fired to a higher temperature as indicated by the type D texture in the exterior zone of the pellets.

All pellets show at least slight to moderate overfiring as indicated by types C and D textures in the outer portions of the zoned pellets.

The typical hematite recrystallization size, the typical widths of quartz reactions rims and the diameters of slag pools (shown in the tables) seem to confirm, in general, the firing degree of the pellets in all samples as indicated by the textural types.

Intergranular magnesioferrite is more abundant than pseudomorphic magnesioferrite in sample P-3D than in the other two samples. This seems to confirm that solutions were mobilized to a higher degree due to a higher temperature.

Finally, the porosity increases from sample P-1 to sample P-3D. The additives have a direct bearing on this feature.

ANNEX

PHOTOMICROGRAPHS

PLATE 1

Photomicrography 1:

Sample P-1 : Textural type C/M (in some pellet core centers) Magnetite (residual, MG) and hematite (H) form, together, a C textural type where as the hematite, itself, with slag (S) shows type M

Photomicrography 2:

Sample P-1 : Textural type M (in pellet cores)
Hematite (H), slag (S), magnesioferrite (M)

Photomicrography 3:

Sample P-1 : Textural type M (in pellet cores)
Hematite (H), slag (S), magnesioferrite (pseudomorphic, Mp, and intergranular, Mi)

Photomicrography 4:

Sample P-1 : Textural type C (exterior zone of pellets)
Hematite (H), quartz (Q), slag (S)

1

2

3

4

PLATE 2

Photomicrography 5:

Sample P-1 : Textural type M (in pellet cores)
Hematite (H), slag (S), magnesioferrite (pseudomorphic, M)

Photomicrography 6:

Sample P-1 : Textural type C (exterior zone of pellets)
Hematite (H), quartz (Q), slag (S)

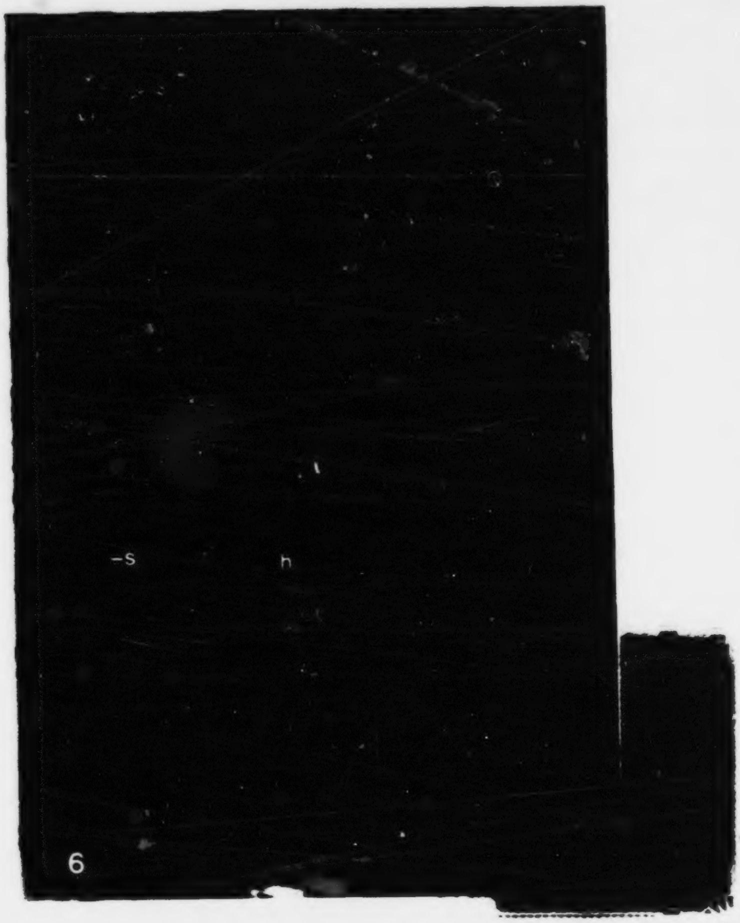
Photomicrography 7:

Sample P-2B: Textural type C/D (exterior zone of pellets)
Hematite (H), quartz (Q), slag (S)

Photomicrography 8:

Sample P-2B: Textural type C/D (exterior zone of pellets)
Hematite (H), slag (S), magnesioferrite (M)

5



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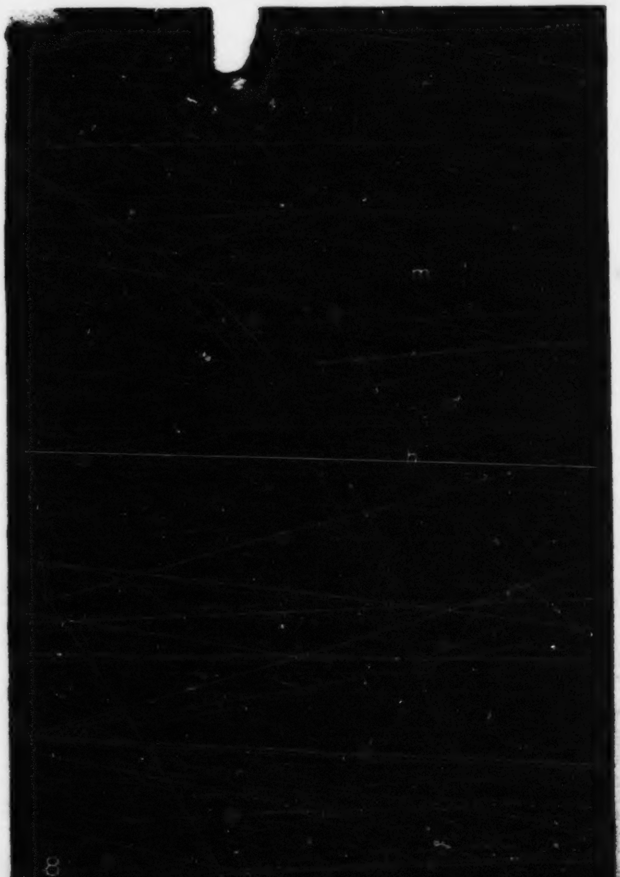

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PLATE 3

Photomicrography 9:

Sample P-2B: Textural type M (in pellet cores)
Hematite (H), slag (S), magnesioferrite (M)

Photomicrography 10:

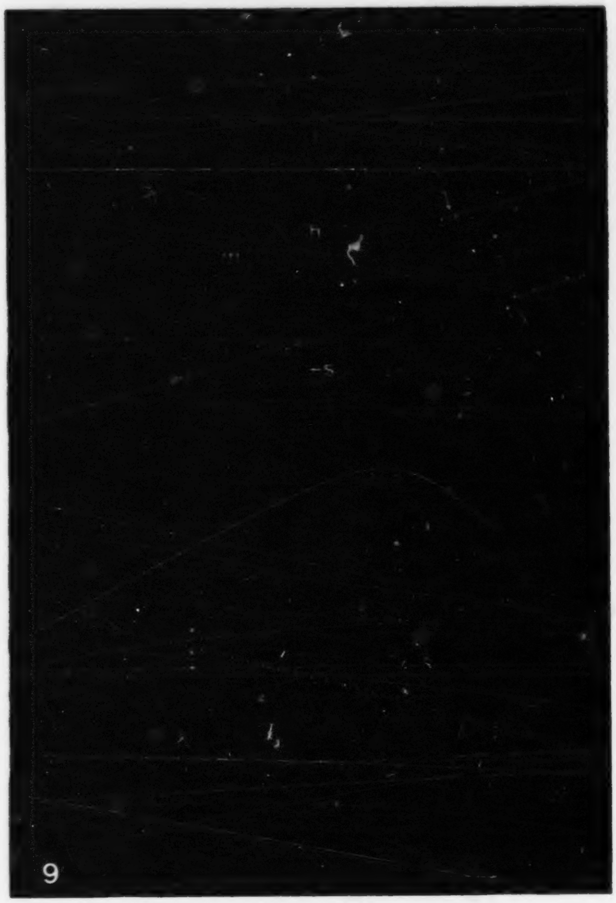
Sample P-2B: Textural type C/D (exterior zone of pellets)
Hematite (H), slag (S)

Photomicrography 11:

Sample P-2B: Textural type M (in pellet cores)
Hematite (H), slag (S)

Photomicrography 12:

Sample P-3D: Textural type M (in pellet cores)
Hematite (H), slag (S)



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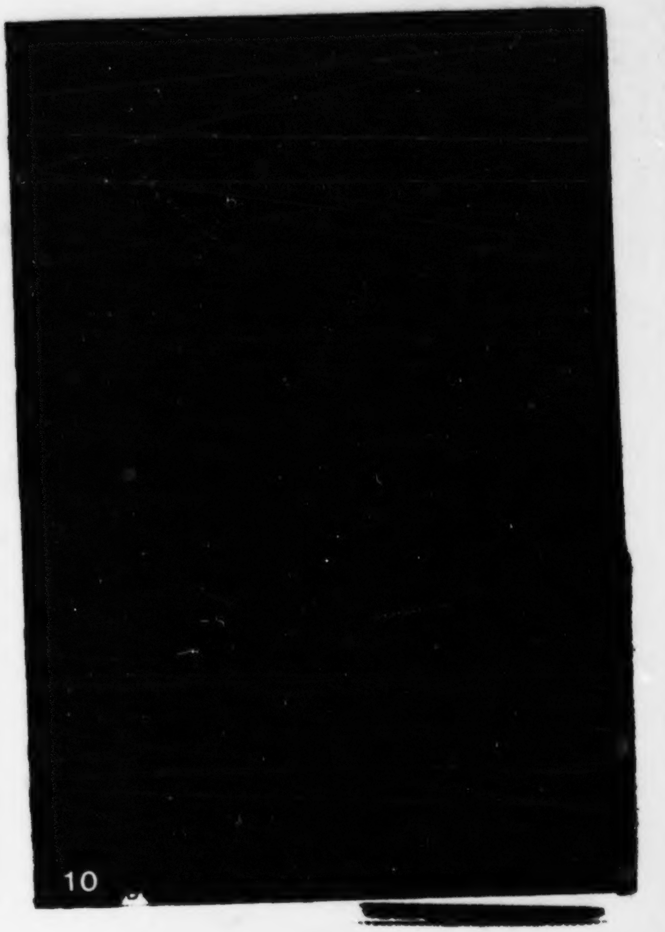

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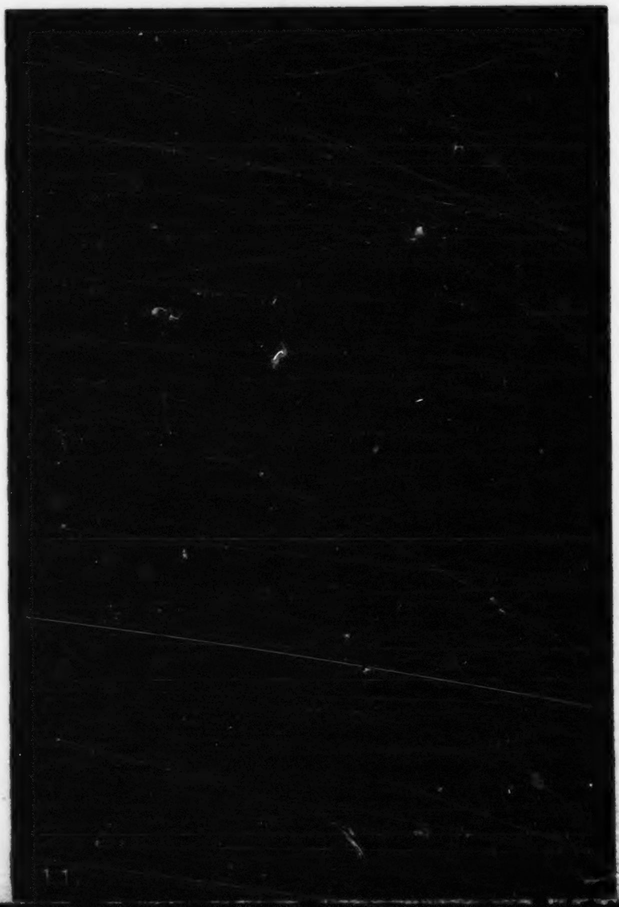

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PLATE 4

Photomicrography 13:

Sample P-3D: Textural type M (in pellet cores)
Hematite (H), slag (S)

Photomicrography 14:

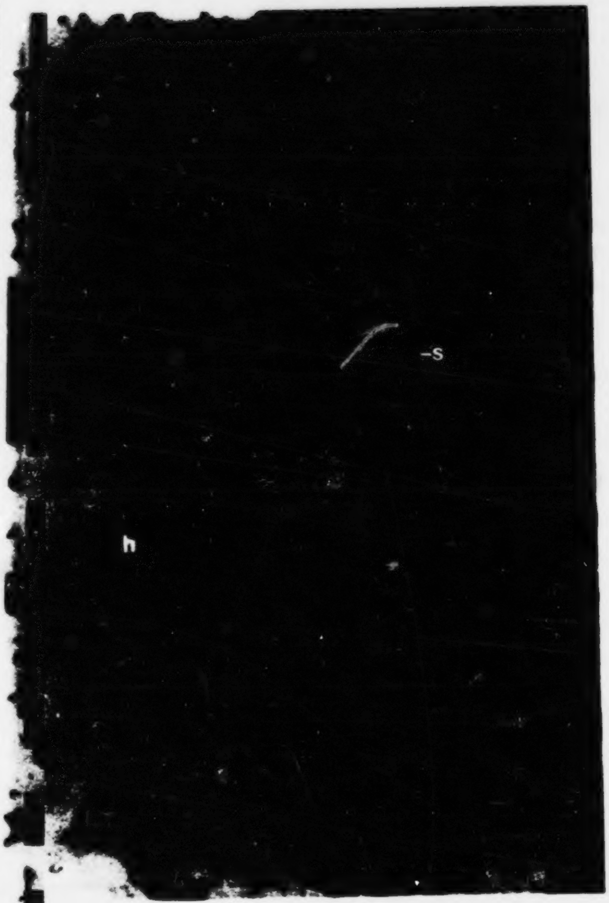
Sample P-3D: Textural type D (exterior zone of pellets)
Hematite (H), slag (S)

Photomicrography 15:

Sample P-3D: Textural type M (in pellet cores)
Hematite (H), slag (S)

Photomicrography 16:

Sample P-3D: Textural type D (exterior zone of pellets)
Hematite (H), slag (S)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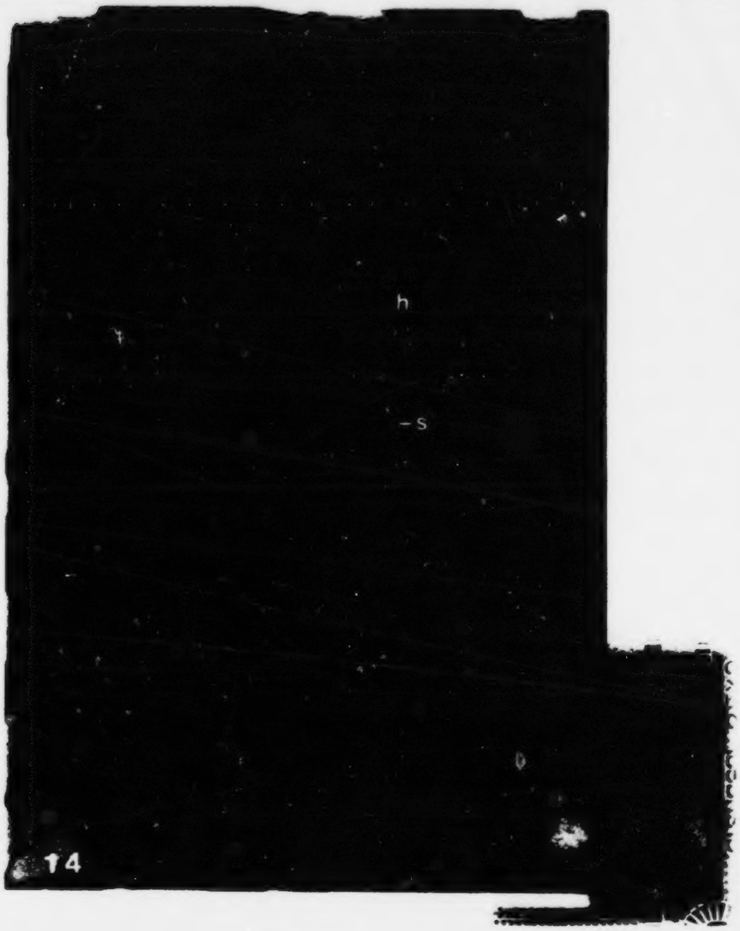
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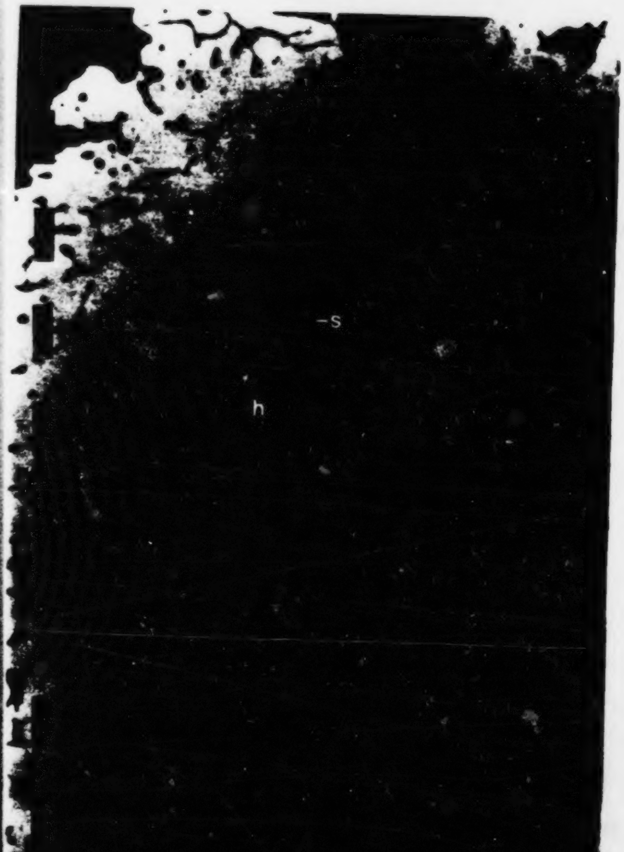
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Appendix 5

Calculation of flux addition in test series # 6 and # 7

Calculation of flux addition in test series #6 and #7

Chemistry required: $MgO = 1.7 \pm 0.1$

$SiO_2 = 5.0$

$CaO/SiO_2 = 0.95 \pm 0.1$

*** Assumption: Organic binders are completely volatilized**

	SiO_2	CaO	MgO	Al_2O_3	After L O I
Concentrate 100g 100%	**4.82**	**0.55**	**0.53**	**0.08**	**99.00**
Dolomite 6g 6%	**0.09**	**1.81**	**1.21**	**0.02**	**3.15**
Limestone 4g 4%	**0.08**	**2.12**	**0.02**	**0.02**	**2.25**
Total (g)	**4.99**	**4.48**	**1.76**	**0.12**	**104.40**
% in F.P.	**4.78**	**4.29**	**1.69**	**0.11**	

Chemistry obtained: $MgO = 1.69$

$SiO_2 = 4.78$

$CaO/SiO_2 = 0.90$

$$B = \frac{CaO + MgO}{SiO_2 + Al_2O_3} = 1.22$$